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US DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE

**TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371**

ATTORNEYS DOCKET NUMBER
P01,0534

U.S. APPLICATION NO. (if known, see 37 CFR 1.5)

10/030856

INTERNATIONAL APPLICATION NO.
PCT/DE00/02202

INTERNATIONAL FILING DATE
06 JULY 2000

PRIORITY DATE CLAIMED
13 JULY 1999

TITLE OF INVENTION

**SAW FILTER OF THE REACTANCE FILTER TYPE WITH IMPROVED STOP BAND SUPPRESSION AND METHOD
FOR OPTIMIZING THE STOP BAND SUPPRESSION**

APPLICANT(S) FOR DO/EO/US

Peter SELMEIER

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay.
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of International Application as filed (35 U.S.C. 371(c)(2)).
 - a. ☒ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. §371(c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). **On behalf of the inventor(s), priority is claimed from German application no. 199 32 649.5, filed July 13, 1999.**
10. ☒ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98; (PTO 1449, Prior Art, Search Report, 07 References).
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 C.F.R. 3.28 and 3.31 is included.
(SEE ATTACHED ENVELOPE)
13. ☒ Preliminary Amendment A prior to action
☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☒ A substitute specification and substitute specification mark-up.
15. ☐ A change of address letter attached to the Declaration.
16. ☒ Other items or information:
 - a. ☒ Submission of Drawings - 18 sheets of drawings, Figures 1-31
 - b. ☒ EXPRESS MAIL #EL 843743033 US dated January 10, 2002

10/030856

U.S. APPLICATION NO. (if known, see 37 C.F.R. 1.5)

INTERNATIONAL APPLICATION NO
PCT/DE00/02202ATTORNEY'S DOCKET NUMBER
P01,053417. ☒ The following fees are submitted:**BASIC NATIONAL FEE (37 C.F.R. 1.492(a)(1)-(5):**

Search Report has been prepared by the EPO or JPO \$890.00

International preliminary examination fee paid to USPTO (37 C.F.R. 1.482) \$710.00

No international preliminary examination fee paid to USPTO (37 C.F.R. 1.482) but international search fee paid to USPTO (37 C.F.R. 1.445(a)(2)) \$740.00

Neither international preliminary examination fee (37 C.F.R. 1.482) nor international search fee (37 C.F.R. 1.445(a)(2)) paid to USPTO \$1040.00

International preliminary examination fee paid to USPTO (37 C.F.R. 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) \$100.00

ENTER APPROPRIATE BASIC FEE AMOUNT =

CALCULATIONS

PTO USE ONLY

\$ 890.00

Surcharge of \$130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(e)).

\$

Claims

Number Filed

Number
Extra

Rate

Total Claims

11

- 20 =

0

X \$ 18.00

\$

Independent Claims

01

- 3 =

0

X \$ 84.00

\$

Multiple Dependent Claims

\$280.00 +

\$

TOTAL OF ABOVE CALCULATIONS =

\$ 890.00

Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 C.F.R. 1.9, 1.27, 1.28)

\$

SUBTOTAL =

\$ 890.00

Processing fee of \$130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +

\$

TOTAL NATIONAL FEE =

\$ 890.00

Fee for recording the enclosed assignment (37 C.F.R. 1.21(h)) The assignment must be accompanied by an appropriate cover sheet (37 C.F.R. 3.28, 3.31) \$40.00 per property +

TOTAL FEES ENCLOSED =

\$ 890.00

Amount to be
refunded

\$

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a. ☒ A check in the amount of \$ 890.00 to cover the above fees is enclosed.b. ☐ Please charge my Deposit Account No. _____ in the amount of \$ _____ to cover the above fees. A duplicate copy of this sheet is enclosed.c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **50-1519**. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 C.F.R. 1.494 or 1.495 has not been met, a petition to revive (37 C.F.R. 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:SCHIFF HARDIN & WAITE
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BOX PCT
IN THE UNITED STATES DESIGNATED/ELECTED OFFICE
OF THE UNITED STATES PATENT AND TRADEMARK OFFICE
UNDER THE PATENT COOPERATION TREATY--CHAPTER II

PRELIMINARY AMENDMENT A
PRIOR TO ACTION

APPLICANT(S): Peter SELMEIER
ATTORNEY DOCKET NO.: P01,0534
INTERNATIONAL APPLICATION NO: PCT/DE00/02202
INTERNATIONAL FILING DATE: 06 JULY 2000
INVENTION: SAW FILTER OF THE REACTANCE FILTER TYPE
WITH IMPROVED STOP BAND SUPPRESSION AND
METHOD FOR OPTIMIZING THE STOP BAND
SUPPRESSION

Assistant Commissioner for Patents,
Washington D.C. 20231

Sir:

Applicants herewith amend the above-referenced PCT application, and
request entry of the Amendment prior to examination on the United States
Examination Phase.

IN THE CLAIMS:

On substitute page 21:

replace line 1 with --WHAT IS CLAIMED IS:--;

Please cancel claims 1-7 without prejudice or disclaimer.

Please add the following claims 8-18.

8. (New) A surface-active wave (SAW) filter of a reactance filter type,
comprising:

a first SAW resonator in a parallel branch of the filter that has a static
capacitance;

a further first SAW resonator in a further parallel branch of the filter that has a
static capacitance;

a second SAW resonator in a serial branch of the filter that has a static capacitance;

at least one basic element fashioned on a piezoelectric substrate, the basic element comprising the first SAW resonator and the second SAW resonator;

5 an electrical connection of ground sides of the first SAW resonator and of the further first SAW resonator (collectively, two first resonators), the electrical connection of the ground sides configured to be made before bonding to a housing that contains the filter; and

10 a bump connection on a housing link of the two electrically connected ground sides of the two first resonators;

wherein at least the static capacitance of the first SAW resonator and the static capacitance of the further first saw resonator differ from one another.

15 9. (New) The SAW filter according to claim 8, wherein the electrical connection comprises a stripline on the substrate.

10. (New) The SAW filter according to claim 8, wherein the electrical connection comprises a bond connection between two pads on the substrate.

20 11. (New) The SAW filter according to claim 8, wherein at least one of the first SAW resonator and the further SAW resonator is divided into two individual parallel resonators, and an output side of one of the individual parallel resonators is electrically connected to the first resonator at the ground side.

25 12. (New) The SAW filter according to claim 8, wherein the housing link of the electrically connected ground sides of at least two parallel resonators comprises a bond connection.

30 13. (New) The SAW filter according to claim 8, wherein the filter is configured to be installed in a housing via a flip-chip technique.

14. (New) The SAW filter according to claim 13, wherein the overall filter size is smaller than or equal to $2.5 \times 2.0 \text{ mm}^2$.

15. (New) A method for operating the SAW filter according to claim 8,
5 comprising:

shifting a pole point in the SAW filter;

raising or lowering the static capacitance of at least one of the first SAW resonator and the further first SAW resonator; and

10 raising or lowering a static capacitance of one or more further, non-coupled first resonators such that an overall sum of the static capacitances of all parallel resonators remains identical.

16. (New) A method according to claim 15, further comprising:

15 raising or lowering the static capacitance of the second SAW resonator to a starting value; and,

raising or lowering, for compensation, a static capacitance of one or more further, second resonators lying in the serial branch between the coupled first resonators such that an overall sum of the static capacitances of all series resonators remains identical.

17. (New) A method according to claim 15, further comprising:

dividing at least one of the first SAW resonator and a further first SAW resonator into two coupled resonators that are parallel to one another, each of the coupled resonators having static capacitance; and

25 setting a frequency position of a coupled pole point by varying a ratio of the static capacitance of the two coupled resonators.

18. (New) A method according to claim 15, further comprising:

30 varying a product of the static capacitances and of the first SAW resonator and the further SAW resonator in such a way that that the static capacitance of a first resonator is raised by a same amount by which the static capacitance of the

further first resonator is lowered, so that a sum of the static capacitances remains identical.

REMARKS

The present Amendment revises the specification and claims to conform to
5 United States patent practice, before examination of the present PCT application in
the United States National Examination Phase. Pursuant to 37 CFR 1.125 (b),
applicants have concurrently submitted a substitute specification, excluding the
claims, and provided a marked-up copy. All of the changes are editorial and
applicant believes no new matter is added thereby. The amendment, addition,
10 and/or cancellation of claims is not intended to be a surrender of any of the subject
matter of those claims.

Early examination on the merits is respectfully requested.

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SPECIFICATION

TITLE

SAW FILTER OF THE REACTANCE FILTER TYPE WITH IMPROVED STOP BAND SUPPRESSION AND METHOD FOR OPTIMIZING THE STOP BAND SUPPRESSION

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] The present invention is directed to a surface-active wave filter (SAW) and, specifically, to a SAW filter of the reactance filter type with improved stop band suppression as well as to a method for the optimization of the stop band suppression.

DESCRIPTION OF THE RELATED ART

[0002] Reactance filters are known from classical filter technology. When SAW resonators are employed for the individual resonators instead of discrete elements (inductors and capacitors), then this is called a SAW filter according to the reactance filter type.

[0003] Given SAW filters of the reactance filter type, SAW resonators are employed as impedance elements. Figure 1 shows the schematic structure of a known resonator. It comprises metallic structures on the surface of a piezo-electric substrate and has a terminal pair 1-1 and 1-2 to which an interdigital transducer 1-4 is connected for the transformation of electrical energy into acoustic energy. A reflector 1-3 and 1-5 is respectively arranged at both sides of the interdigital transducer 1-4 along the acoustic axis in order to prevent the acoustic energy from escaping.

[0004] Figure 2, on the left, shows the equivalent circuit diagram for a SAW resonator R and shows the symbol employed for the resonator at the right. A series resonant circuit composed of dynamic inductance L_1 , dynamic capacitor C_1 and dynamic resistor R_1 (when taking losses into consideration) is located in the first branch of the parallel circuit, and the static capacitor C_0 of the interdigital transducer is located in the second branch. The series resonant circuit reflects the behavior of the resonator in the resonance case, i.e., in the range of the resonant frequency f_r . The static capacitor reflects the behavior in the frequency ranges $f \ll f_r$ and $f \gg f_r$. The dynamic capacitor C_1 is proportional to the static capacitor C_0 of the interdigital transducer:

[0005] $C_1 \sim C_0$ (1.1)

[0006] A resonator has a resonant frequency f_r and an anti-resonant frequency f_a . The following applies to the resonant frequency f_r :

$$f_r = \frac{1}{2\pi} \sqrt{L_1 * C_1} \quad (1.2)$$

[0008] The following applies for the anti-resonant frequency f_a of a resonator:

$$f_a = f_r * \sqrt{1 + \frac{C_1}{C_0}} \quad (1.3)$$

[0010] The basic unit of a SAW reactance filter is a “basic element” as shown in Figure 3. It is composed of a first resonator R_1 with resonant frequency f_{rp} and appertaining anti-resonant frequency f_{ap} in the parallel branch and of a second resonator R_2 with resonant frequency f_{rs} and appertaining anti-resonant frequency f_{as} in the serial branch. The frequency curve of the admittance Y_p of the resonator R_1 in the parallel branch and the frequency curve of the impedance Z_s of the resonator R_2 in the serial branch are shown in Figure 4. For producing a band-pass filter with the middle frequency f_0 , the resonant frequencies of the two resonators have the following relationship:

$$f_{ap} \approx f_{rs} \approx f_0 \quad (1.4)$$

[0012] Each basic element is fundamentally viewed as a two-port element with the terminals 3-1 or 3-2 of port 1 and the terminals 3-3 or 3-4 of port 2 (see Figure 3). At the same time, the terminal 3-1 is the input and the terminal 3-3 is the output of the series resonator. The input of the parallel resonator is connected to the terminal 3-1. The terminals 3-2 and 3-4 represent the reference ground for an asymmetrical operation. The output 3-4 of the parallel resonator that faces toward the reference ground is referred below as the output side or ground side of the parallel resonator. The inductance L_{ser} that lies between the output side of the parallel resonator and the reference ground reflects the connection to the housing ground in the real structure.

[0013] The selection level of the SAW filter according to the reactance filter type is defined, first, by the relationship C_{op}/C_{os} of static capacitor C_{op} in the parallel branch and static capacitor C_{os} in the series branch and is defined, second, by the number of basic elements connected following one another (in a cascaded manner, i.e., in series).

[0014] The basic elements when they are connected in series are usually circuit-adapted, i.e., they are respectively mirrored. Figure 5 and Figure 6 show two examples of a reactance filter in which respectively two basic elements are cascaded. The output impedance 5-1 (Z_{out}) or 6-1 (Z_{in}) of the first basic element is equal to the input impedance 5-2 or 6-2 of the second basic element, resulting in a minimization of losses due to mismatching. Many structures are possible or known for reactance filters with respect to the number and arrangement of the basic elements.

[0015] Resonators of the same type (series resonator or parallel resonator) lying immediately behind one another can also be respectively combined to form one in which the overall capacitance remains the same. The interconnection of a filter according to Figure 7 corresponds in effect to that of a filter according to Figure 8.

[0016] Figures 9 and 10 show the typical, actual structure of a SAW filter on a piezoelectric substrate 9-1 in a ceramic housing 9-0 and the typical connecting technique with bond wires 9-8 through 9-12 or 10-9.

[0017] At the output side 9-15 through 9-17, the parallel resonators R1, R3 and R5 are connected to the housing ground pads 9-4, 9-5 and 9-7 via bond wires 9-9, 9-10 and 9-12.

[0018] As a result of the typical structuring technique (see Figure 9 and Figure 10), series inductances between, for example, the output side 9-17 of the parallel resonator R5 on the substrate (chip) 9-1 and the ground 10-5 next to the outer housing pin 9-4 are obtained given the connection of the parallel branches to ground. These essentially include the inductive part of the stripline on the chip, the inductance of the bond connection 9-9 and that of the housing lead-through 10-3.

[0019] These series inductances influence the behavior of the filter both in the passband as well as in the stop band. $f \ll f_0$ applies for the pass band. The resonant frequency and, thus, the bandwidth of a resonator can, as known, be modified by an external wiring belonging to the resonator. An inductance serially with the resonator increases the effective dynamic inductance, resulting in a drop in the resonant frequency f_r . Since the anti-resonant frequency f_a is shifted to only a very slight extent, the bandwidth $\Delta f = f_a - f_r$ of a resonator is increased with the serial inductance. The bandwidth of the SAW filter is also increased in the case of a parallel resonator.

[0020] $f < f_0$ and $f > f_0$ applies for the stop band. Here, the equivalent circuit diagram of a resonator is reduced to its static capacitance C_0 since the series resonant circuit is extremely high-impedance beyond f_0 and corresponds to a no-load condition. An inductance L_{ser} connected serially with the resonator produces the series resonant circuit shown in Figure 11b having a resonant frequency

$$f_{pol} = 1/2\pi \sqrt{L_{ser} * C_0} \quad (1.5)$$

[0022] In the case of an inductance connected serially with a parallel resonator, this means that the energy of the filter can flow off directly to ground given the frequency f_{pol} ; a "pole point" thus forms in the filter curve, i.e., an increased suppression in the stop band. A plurality of pole points in the stop band corresponds to the plurality of parallel branches with series inductance. Pole points f_{pol1} and f_{pol2} that can be distinguished from one another in terms of frequency derive only given different products $\Pi_1 = L_{ser1} * C_{01}$ and $\Pi_2 = L_{ser2} * C_{02}$. When the products are identical, then the pole points lie at the same frequency; a double pole point $f_{pol} = f_{pol1} = f_{pol2}$ is obtained with a higher suppression than that of a simple single pole point.

[0023] Figure 11b shows the attenuation behavior of a resonator in the parallel branch to which an inductance L_{ser} is serially connected at the output side of the parallel resonator. As in Figure 11b, the series resonant circuit of the resonator (whose resonant frequency $f_{rp} = f_0$) was removed in order to illustrate the pole point. What typically applies for the frequency of the pole point f_{pol} is $f_{pol} > f_0$, where f_0 is equal to the resonant frequency of the filter. A high attenuation is then obtained for the pole point.

[0024] SAW filters of the reactance filter type are mainly employed as RF filters in the mobile radio telephone field since they exhibit extremely low losses in the pass band. As an RF filter in the mobile radio telephone field, the SAW filter of the reactance filter type must, over and above this, suppress: first, the duplex band (i.e., the reception band given a transmission filter and, conversely, the transmission band given a reception filter); and, second, the signal at the local oscillator frequency (LO) and/or at the image frequency in order to prevent unwanted mixed products in the telephone.

[0025] The local oscillator lies above or below the middle frequency f_0 of the filter. The distance from the middle frequency f_0 corresponds to the intermediate frequency (ZF) employed for the signal editing. The image frequency has the spacing $2*ZF$ from the middle

frequency f_0 . Since momentary ZF frequencies in the range of 100-400 MHz are employed, the SAW filter - depending on the application - must comprise good attenuation properties of, typically, more than 30 dB in the range $f_0 \pm 100$ -800 MHz. In the most frequent instances, the local oscillator lies above the middle frequency f_0 .

[0026] There are various possibilities for achieving an adequate attenuation in the range of the LO frequency and/or image frequency. According to a first possibility, the general selection level may be made correspondingly high (the minimum attenuation below the pass band given approximately $f_0/2$ is valid as a criterion for this). The great disadvantage in this situation is, however, that the losses in the pass band also increase with an increasing selection level. This is unacceptable for the signal processing in the telephone in most cases.

[0027] The second possibility is based on the previously mentioned fact that an inductance present for the traditional structuring technique generates a pole point serially with a parallel resonator that lies exactly at the LO or image frequency. Given the great spectrum of ZF frequencies employed, a possibility must be established in this case in order to vary the generated pole point over a range of approximately 700 MHz.

[0028] Since the static capacitance C_{op} in the parallel branch is the determining factor for the filter performance (passband, matching and selection level), the pole point can only be varied to an extremely slight degree with given filter demands such that the position of pole points in the stop band also simultaneously changes.

[0029] Likewise, the degree of freedom for the size of the inductance serially between output side of the parallel resonator and ground is limited. The inductive part of the stripline on the chip can be varied to only a limited extent, due to the necessity for miniaturization as well as for cost reasons, the chips that are employed are becoming smaller and smaller. The length and the inductance of the associated bond connection can likewise hardly be varied any more with any housing in the course of the progressing trend towards miniaturization. Moreover, the inductance that derives from the housing lead-through is fixed for a given housing.

[0030] This second possibility is thus also not established anymore to an adequate extent for SAW filters according to the reactance filter type in housings that have been miniaturized further. This possibility is no longer established to an adequate degree in order

to assure the LO and/or image suppression via suitably placed pole points over a great frequency range from f_0 plus 100-800 MHz.

[0031] It is impossible to generate pole points at relatively low frequencies (i.e., in the range of 100 MHz above the middle frequency f_0), particularly given the future connection technology of "flip-chip-technique" in which bump connections are employed instead of the bond wires, since the inductances present given this structuring technique serially to the output side of a parallel resonator are too small (see Equation 1.5), and the static capacitances of the parallel branches can likewise not be selected great enough because of the required self-matching to 50Ω .

SUMMARY OF THE INVENTION

[0032] It is therefore an object of the present invention to provide a way of designing a filter such that an improved stop band suppression can be obtained for specific LO frequencies and image frequencies over a possible range from 100 through 800 MHz next to the middle frequency. In particular, a way is provided for shifting pole points of a reactance filter into a desired region close to the middle frequency f_0 without greatly influencing the remaining filter behavior.

[0033] This object is achieved by a surface-active wave (SAW) filter of a reactance filter type, comprising a first SAW resonator in a parallel branch of the filter that has a static capacitance; a further first SAW resonator in a further parallel branch of the filter that has a static capacitance; a second SAW resonator in a serial branch of the filter that has a static capacitance; at least one basic element fashioned on a piezoelectric substrate, the basic element comprising the first SAW resonator and the second SAW resonator; an electrical connection of ground sides of the first SAW resonator and of the further first SAW resonator (collectively, two first resonators), the electrical connection of the ground sides configured to be made before bonding to a housing that contains the filter; and a bump connection on a housing link of the two electrically connected ground sides of the two first resonators; wherein at least the static capacitance of the first SAW resonator and the static capacitance of the further first saw resonator differ from one another.

[0034] This object is also achieved by a method for operating this SAW filter, comprising shifting a pole point in the SAW filter; raising or lowering the static capacitance of at least one of the first SAW resonator and the further first SAW resonator; and raising or

lowering a static capacitance of one or more further, non-coupled first resonators such that an overall sum of the static capacitances of all parallel resonators remains identical.

[0035] A coupling of the parallel branches is inventively produced as a result of a connection of the ground-side output sides of the parallel branches respectively comprising a resonator on the chip. This permits a greatly modifiable frequency positioning of the appertaining pole point (also referred to as "coupled pole point" below).

[0036] As a result, it is possible to produce a SAW filter that comprises pole points at lower frequencies than could be achieved by the previous, serial interconnection of the parallel branches with existing, structure-conditioned inductances according to Equation (1.5). It is also possible to shift one or more pole points in a given filter over a broader frequency range than was previously possible in a given filter. With the invention, thus, a pole point can be generated at exactly the frequency at which a high selection is required, for example, at an arbitrary LO or image frequency.

[0037] Such demands for the suppression of signals at the local oscillator frequency (LO suppression) and/or at the image frequency (image suppression) can thus still be satisfied in extremely small housings having very low structure-conditioned inductances. One or more pole points can be shifted to a desired frequency given an established bond inductance, conduct inductance or housing lead-through inductance without this requiring an increase in the serial inductance. Additionally, of course, the serial inductance can also be increased.

[0038] Moreover, the plurality of ground connections that are offered can be set independently of the plurality of parallel branches employed, this leading to a lower space requirement. It is precisely in view of new connecting technologies (bump connections instead of bond connections) and new housing technologies that the embodiments according to the invention represent the sole possibility for achieving the previously mentioned selection demands in miniaturized housings.

[0039] The principle for shifting the pole points according to the present invention is explained in greater detail below on the basis of exemplary embodiments and the appertaining figures. The following, concrete embodiments are examples of the employment in a SAW filter of the reactance filter type.

DESCRIPTION OF THE DRAWINGS

Fig. 1 is a pictorial diagram of a one-port SAW resonator;

- Fig. 2 is the equivalent circuit diagram and symbol for a SAW resonator;
- Fig. 3 is a schematic diagram showing a basic element of a SAW filter of the reactance filter type;
- Fig. 4 is a graph illustrating the interaction of parallel and series resonators;
- Fig. 5 is a schematic diagram showing a cascade of two basic elements;
- Fig. 6 is a schematic diagram showing a cascade of two basic elements ;
- Fig. 7 is a schematic diagram of a reactance filter;
- Fig. 8 is a schematic diagram of a reactance filter with the reduced structure s-p-s-p;
- Fig. 9 is a plan view of a SAW filter into the housing without cover;
- Fig. 10 is a cross-section view through a SAW filter in the housing;
- Fig. 11a is a graph illustrating the pole point;
- Fig. 11b is an equivalent circuit diagram for the attenuation behavior of a parallel branch;
- Fig. 12 is an equivalent circuit diagram of an inventive filter;
- Fig. 13 is an equivalent circuit diagram for the attenuation behavior of a SAW filter;
- Fig. 14 is a graph showing the relationship between ΔL_{ser} and the pole point;
- Fig. 15 is a graph showing the dependency of the frequency position of the pole point on the static capacitance;
- Fig. 16 is a schematic diagram of a first embodiment of a filter having three basic elements;
- Fig. 17 is an equivalent circuit diagram of the first embodiment circuit shown in Fig. 16 in the stop band;
- Fig. 18 is a graph illustrating the attenuation behavior of the first embodiment circuit shown in Fig. 16;
- Fig. 19 is a schematic diagram of a second embodiment of a filter with four basic elements;
- Fig. 20 is an equivalent circuit diagram of the second embodiment circuit shown in Fig. 19 in the stop band;
- Fig. 21 is a graph illustrating the attenuation behavior of the second embodiment circuit shown in Fig. 19;
- Fig. 22 is a schematic diagram of a third alternative embodiment of a filter with four basic elements;
- Fig. 23 is an equivalent circuit diagram of the third embodiment circuit shown in Fig. 22 in the stop band;

- Fig. 24 is a graph illustrating the attenuation behavior of the third embodiment circuit shown in Fig. 22;
- Fig. 25 is a schematic diagram of a fourth embodiment alternative embodiment of a filter with four basic elements;
- Fig. 26 is an equivalent circuit diagram of the fourth embodiment circuit shown in Fig. 25 in the stop band;
- Fig. 27 is a graph illustrating the filter characteristic of the fourth embodiment circuit shown in Fig. 25;
- Fig. 28 is a schematic diagram of a fifth alternative embodiment of a filter with four basic elements;
- Fig. 29 is an equivalent circuit diagram of the fifth embodiment circuit shown in Fig. 28 in the stop band;
- Fig. 30 is a plan view of the filter structure in a sixth embodiment with a bump connection; and
- Fig. 31 is a plan view of the filter structure with a bond connection.

DETAILED DESCRIPTION OF THE INVENTION

[0040] Fig. 12 shows a simple filter structure of the invention symbolically as an equivalent circuit diagram, which may be part of a larger filter structure with further basic elements. For a filter circuit having (at least) two of the parallel branches with the parallel resonators R2 and R3, the output sides 12-6 and 12-7 are already inventively electrically connected to one another on the chip itself (substrate) 12-8. Only after such a connection is present does one make a connection to the housing ground pad 12-4 comprising, for example, a bond connection 12-5.

[0041] Fig. 13 shows the equivalent circuit diagram for the frequency range $f \ll f_0$ and $f \gg f_0$ where only the static capacitance C_0 takes effect for each resonator. The selection behavior of a SAW filter according to the reactance filter type can be largely described with this reduced equivalent circuit diagram. The inductance L_{ser} corresponds to the inductance between the connection of the parallel resonators on the chip and the housing ground pin (equals terminal for ground at the housing) outside.

[0042] The coupling of the two parallel branches already electrically connected on the chip that occurs leads to a frequency position change of the pole points in the stop band. The frequency position of the coupled pole point can be identified based on the equivalent circuit

diagram from Figure 13 which shows a two port circuit Z. The two port circuit Z comprises a pole point when the impedance to ground becomes zero.

[0043] $Z_{21} = 0$

[0044] where Z_{21} is a systematically referenced matrix element from the impedance matrix. For determining Z_{21} , the two port circuit Z can be divided into a series circuit of the two-ports Z' and Z'' . The two-port Z' comprises the Π -circuit composed of the three capacitors C_{op1} , C_{op2} and C_{os} . The two-port Z'' comprises only the inductance L_{ser} . The following thus derives:

[0045]

[0046]
$$Z'_{21} = \frac{1}{j\omega \left(C_{op2}C_{op1} + \frac{C_{op1}C_{op2}}{C_{os}} \right)} \quad (2.1)$$

[0047]
$$Z''_{21} = j\omega L_{ser} \quad (2.2)$$

[0048] Where j represents the imaginary number and $\omega = 2\pi f$ applies.

[0049] With

[0050] $Z_{21} = Z'_{21} + Z''_{21} \quad (2.3)$

[0051] it follows that

[0052]
$$Z_{21} = \frac{1 - \omega^2 L_{ser} \left(C_{op2} + C_{op1} + \frac{C_{op1}C_{op2}}{C_{os}} \right)}{j\omega \left(C_{op2} + C_{op1} + \frac{C_{op1}C_{op2}}{C_{os}} \right)} \quad (2.4)$$

[0053]

[0054] When the numerator of the expression of (2.4) becomes zero,

[0055]
$$1 - \omega^2 L_{ser} \left(C_{op2} + C_{op1} + \frac{C_{op1}C_{op2}}{C_{os}} \right) = 0 \quad (2.5)$$

[0056] Z_{21} becomes zero. The following derives for the frequency position of the coupled pole point:

$$f_{pol} \text{ (coupled)} = \frac{1}{2\pi\sqrt{L_{ser}\left(C_{op2} + C_{op1} + \frac{C_{op1}C_{op2}}{C_{os}}\right)}} \quad (2.6)$$

[0057]

[0058]

[0059] It can be clearly seen compared to the pole points previously obtained without coupling of the parallel branches on the chip according to Equation (1.5).

(2.7)

$$f_{pol2} = \frac{1}{2\pi\sqrt{L_{ser} * C_{op2}}} \quad (2.8)$$

[0060] $\frac{C_{op1}C_{op2}}{C_{os}}$

[0061] That the additional capacitance parts $\frac{C_{op1}C_{op2}}{C_{os}}$ and C_{op2} or C_{op1} shift the coupled pole point to a far lower frequency given the same inductance L_{ser} .

[0062] To illustrate with a numerical example: for a known SAW filter of the reactance filter type, the frequency f_{pol} of a pole point is calculated as:

$$f_{pol1} = \frac{1}{2\pi\sqrt{L_{ser} * C_{op1}}} = \frac{1}{2\pi\sqrt{1nH * 4pF}} = 2.52 \text{ GHz}$$

[0063]

[0064] Typical values of 1nH and 4pF are assumed in this example for the serial inductance L_{ser} and for the static capacitance C_{op} .

[0065] According to Equation 2.6 and given the same assumed values for L_{ser} and C_{op} and likewise given 4pF for C_{os} ,

[0066]

$$f_{pol2} = \frac{1}{2\pi\sqrt{1nH * (rpF + 4pF + (4pF)^2 / 4pF)}} = 1.45 \text{ GHz}$$

[0067]

[0068] derives when two parallel branches are coupled.

[0069] When a filter comprises a plurality of parallel branches, then a plurality of parallel branches can also be connected to one another at the ground side, these are also referred to as "coupled parallel branches". The plurality and combination of the connected parallel branches plays a critical part for the frequency position of the coupled pole points and

is considered in the selection of the filter structure for a desired frequency position of the pole points.

[0070] Fig. 14 indicates the dependency of the position of a coupled pole point on the size of the inductance L_{ser} . The two curves 14-1 and 14-2 indicate the filter behavior for the same filter, where only L_{ser} has been differently selected. A different frequency position of the pole points derives dependent on L_{ser} , where the inductance L_{ser1} belonging to f_{pol1} is smaller than L_{ser2} . The shift of the pole points toward lower frequencies is greater the higher the inductance L_{ser} is.

[0071] To a lesser extent, the frequency position of the pole point can be set by a variation of the product of static capacitances of the coupled parallel branches

$$[0072] \quad \Pi_p C = C_{0p1} * C_{0p2} \quad (2.9)$$

[0073] So that the filter behavior in the passband and the general selection level is not modified, such a variation of the product of static capacitances in the parallel branch can be implemented only upon retention of their sum:

$$[0074] \quad \Sigma C_p = C_{0p1} + C_{0p2} = \text{constant} \quad (2.10)$$

[0075] The following method can be applied: the static capacitance C_{0p1} of the first couple parallel resonator is increased by the same amount C_{const}

$$[0076] \quad C_{0p1}(\text{new}) = C_{0p1} + C_{const} \quad (2.11)$$

[0077] by which the static capacitance C_{0p2} of the second couple parallel resonator is lowered:

$$[0078] \quad C_{0p2}(\text{new}) = C_{0p2} - C_{const} \quad \text{with } C_{const} < C_{0p2}, \quad (2.12)$$

[0079] so that the product ΣC_p in fact changes but the sum of the static capacitances remains identical.

$$[0080] \quad \Sigma C_p = C_{0p1}(\text{new}) + C_{0p2}(\text{new}) = C_{0p1} + C_{0p2} = \text{constant} \quad (2.13)$$

[0081] and no modifications of the passband or of the general selection level need be accepted.

[0082] When a greater frequency offset of the couple pole point is necessary, the participating static capacitances C_{0p1} , C_{0p2} or C_{0s} can be varied. When more parallel resonators than the two parallel resonators to be coupled are present, then the sum $C_{0p1} + C_{0p2}$

can be raised (or lowered), and the static capacitance of a non-coupled parallel resonator can be lowered (or raised) for balancing such that the total sum of all static capacitances remains the same in the parallel branches, thus retaining the general selection level.

[0083] Fig. 15 shows how, given a constant inductance L_{ser} , the frequency of the couple pole point is increased as a result of a reduction of the sum of the static capacitances $C_{0p1} + C_{0p2}$ of the coupled parallel branches being increased by the factor 1.2. For balancing, the static capacitance of a further parallel branch is correspondingly increased.

[0084] Another possibility for shifting the couple pole point is to intentionally split a parallel resonator P into two individual resonators P' and P'' parallel to one another, where the sum of the capacitances of the split, individual resonators is equal to the original capacitances C_{0p} :

[0085]
$$C_{0p} = C'_{0p} + C''_{0p}$$

[0086] When one of these parallel resonators P' is coupled with a further parallel resonator, but not with the parallel resonator P'', then the frequency position of the coupled

$$\frac{C'_{\theta p}}{C''_{\theta p}}$$

pole point can be set on the basis of the division ratio of the static capacitance of the split parallel resonators P' and P'', since C'_{0p} influences the frequency position of the coupled pole point.

[0087] A single series resonator or a plurality of series resonators can be arranged between coupled parallel branches. Since the size of the static capacitance C_{0s} that lies between the coupled parallel resonators influences the frequency position of the coupled pole point according to Equation 2.6, the frequency position of the coupled pole point can likewise be shifted with the following method.

[0088] When further series resonators S_n are present, in addition to the series resonator or resonators S lying between the coupled parallel branches, then the static capacitance C_{0s} can be raised (or lowered). Additionally, for balancing, the static capacitance of the series resonators S_n that do not lie between the coupled parallel resonators can be lowered (or raised) such that the total sum of all static capacitances in the series branches remains the same. This results in retaining the general selection level and modifying the frequency position of the coupled pole point.

[0089] The range for the variation of the static capacitances C_p in the parallel branch and of the serial inductances L_{ser} (between the connection of the parallel branch on the chip and the outside terminal at the housing) is limited. The same is therefore also true for the frequency range in which the pole points can be displaced. In contrast to the measures known from the prior art, however, the range of variation achieved according to the invention enables the manufacture of SAW filters - even given extremely miniaturized housings - with an LO suppression and image suppression that is required for the employment as an RF filter in the mobile radio telephone field.

[0090] Concrete embodiments of inventive filters described below.

FIRST EMBODIMENT

[0091] A first embodiment (Embodiment 1) of the invention, illustrated in Figs. 16-18, uses a structure having three basic elements. A first basic element is connected to the input port 16-1 such that both the parallel branch as well as the series branch comprise a connection to the input port. The second basic element is connected according to the matching demand $Z_{out} = Z_{in}$. The third basic element follows in the same way. Differing from the case at the input port, only one series branch is thus directly connected to the output port. A sequence $p-s - s-p - p-s$ for the resonators is present from the input to the output, where p stands for parallel resonator and s stands for series resonator. Fundamentally, the input port and output port can be interchanged without modifying the filter properties, from which the sequence presented is $s-p - p-s - s-p$.

[0092] As is known in the art, identical resonators can also be combined upon retention of their capacitance. The following structures with a minimum number of resonators thus derive:

[0093] $p-s-p-s$ or $s-p-s-p$

[0094] however, mixed forms having partial combination of the resonators area also possible:

[0095] $p-s-p-p-s$ or $s-p-p-s-p$

[0096] $p-s-s-p-s$ or $s-p-s-s-p$

[0097] For the sake of simplicity, the embodiments below are only explained on the basis of a minimum of resonators and without additional indication of the interchangeability

of the input port and the output port, and are shown this way in the Figures. Nonetheless, the invention also comprises modifications according to the above example.

[0098] Fig. 16 symbolically shows the structure of Embodiment 1. The two parallel branches are already electrically connected to one another on the chip and a connection to the housing only ensues subsequently in the fabrication. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Fig. 17. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside.

[0099] The filter has a filter characteristic as identified by curve 18-1 in Fig. 18. The comparison to filter curve 18-2 (corresponding to the filter shown in Fig. 8) in which the parallel branches on the chip are not connected to one another, clearly shows how the frequency position of the pole points in the stop band with a typical inductance $L_{ser} = 1.0 \text{ nH}$ is shifted by the connection of the parallel branches on the chip. The selection is increased by more than 10 dB in the frequency range between the vertical lines (typical frequency range for LO suppression and image suppression given low intermediate frequency).

SECOND EMBODIMENT

[00100] A second embodiment (Embodiment 2) is illustrated in Figs. 19-21. Fig. 19 symbolically shows the structure of the second inventive embodiment in which a structure having four basic elements is employed. A first basic element is connected to the input port 19-1 such that both the parallel branch as well as the series branch comprise a connection to the input port. The second basic element is connected according to the matching requirement $Z_{out} = Z_{in}$. Basic element 3, 4 follows in the same way. Just as at the input port, both a parallel branch as well as a series branch are directly connected to the output port 19-3. A sequence for the resonators from the input to the output derives as follows:

[00101] $p-s-p-s-p$

[00102] where p stands for parallel resonator and s stands for series resonator. Resonators of the same type are already combined.

[00103] Two of the three parallel branches are already electrically connected to one another on the chip and a connection to the housing only occurs subsequently via the inductance L_{ser2} . The remaining parallel branch is connected to the housing independently via

the inductance L_{ser1} . The equivalent circuit diagram for the selection behavior in the range $f < f_0$ and $f > f_0$ is shown in Fig. 20. The inductance L_{ser2} corresponds to an inductance between the connection 19-4 of the parallel resonators on the chip (shown with the broken line in Fig. 19) and the housing ground pin outside.

[00104] In Fig. 21, the curve 21-1 shows the filter characteristic of the filter from Fig. 19. The comparison with the filter curve 21-2 in which the parallel branches are not connected on the chip clearly shows how the frequency position of the pole points in the stop band, given a typical inductance $L_{ser2} = 1.0 \text{ nH}$, is shifted towards lower frequencies due to the connection of two of the three parallel branches on the chip. The selection is increased by approximately 10 dB in the frequency range between the vertical lines (the typical frequency range for LO suppression and image suppression at a low intermediate frequency).

THIRD EMBODIMENT

[00105] A third embodiment (Embodiment 3) is illustrated in Figs. 22-24. Fig. 22 symbolically shows the structure of the inventive Embodiment 3 in which a structure having three basic elements is employed. A first basic element is connected to the input port 22-1 such that only the series branch comprises a connection to the input port. The second basic element is connected according to the matching requirement $Z_{out} = Z_{in}$. Basic element 3, 4 follows in the same way. Just as at the input port, only one series branch is thus directly connected to the output port 22-3. A sequence for the resonators from the input to the output is as follows:

[00106] $s-p-s-p-s$

[00107] where p stands for parallel resonator s stands for series resonator. Resonators of the same type are already combined.

[00108] The two parallel branches are already electrically connected to one another on the chip and a connection to the housing only occurs subsequently. The equivalent circuit diagram for the selection behavior in the range $f < f_0$ and $f > f_0$ is shown in Fig. 23. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside. The filter from 22 has a filter characteristic as identified by curve 24-1 in Fig. 24. The comparison to the filter curve 24-2, where the parallel branches are not connected on the chip, clearly shows how the frequency position of the pole points in the stop band given a typical inductance $L_{ser} = 1.0 \text{ nH}$ is shifted due to the

connection of the two parallel branches on the chip. The selection is increased by more than 8 dB in the frequency range between the vertical lines (the typical frequency range for LO suppression and image suppression at a high intermediate frequency).

FOURTH EMBODIMENT

[00109] A fourth embodiment (Embodiment 4) is illustrated in Figs. 25-27 in which a structure and four basic elements are employed. A first basic element is connected to the input port 25-1 such that only the series branch having the resonator R_{S1} comprises a connection to the input port. The second basic element is connected in a mirrored fashion because of the matching demand $Z_{out} = Z_{in}$. Basic element 3, 4 follows in the same way. Just as at the input port, only one series branch is thus directly connected to the output port 25-3. A sequence for the resonators from input to output is as follows:

[00110] *s-p-s-p-s*

[00111] Resonators of the same type are already combined; in contrast to Embodiment 3, however, one parallel branch has been intentionally divided again. The division ensues such that each parallel resonator R_{p2} , R_{p3} forms its own two-port with its own electrical inputs and outputs. The combined parallel branch having the resonator R_{p1} together with one of the non-combined, two parallel branches (R_{p2}) are already electrically connected to one another on the chip at 25-2, and a connection to the housing only ensues subsequently in the fabrication via L_{ser1} . The remaining parallel branch (R_{p3}) is connected to the housing independently. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Figure 26. The inductance L_{ser1} corresponds to an inductance between the connection of the parallel resonators R_{p1} and R_{p2} on the chip and the housing ground pin outside; the inductance L_{ser2} corresponds to an inductance between the parallel resonator R_{p3} on the chip and the housing ground pin outside.

[00112] The filter from Fig. 25 has a filter characteristic that is characterized by curve 27-1 in Fig. 27. The comparison to the filter curve 27-2, in which the output sides of the parallel branches are not connected on the chip, clearly shows how the frequency position of the pole points in the stop band given a typical inductance $L_{ser1} = 1.0$ nH is shifted due to the connection of two of the three parallel branches on the chip. The selection is increased generally by more than 5 dB in the frequency range between the vertical lines (the typical frequency range for LO suppression and image suppression given a high intermediate

frequency). The selection gain is far more than 10 dB when either a high LO suppression or image suppression is demanded.

FIFTH EMBODIMENT

[00113] A fifth embodiment (Embodiment 5) of the invention is illustrated in Figs. 28-30. Fig. 28 symbolically shows the structure of the inventive Embodiment 5 in which a structure having four basic elements is employed. A first basic element is connected to the input port 28-1 such that only the series branch comprises a connection to the input port. The second basic element is connected according to the matching demand $Z_{out} = Z_{in}$. Basic element 3, 4 follows in the same way. Just as at the input port, only one series branch is directly connected to the output port 28-3. A sequence for the resonators from input to output derives as follows:

[00114] *s-p-s-p-s*

[00115] Resonators of the same type are already combined similar to embodiment 4; however, one parallel branch is intentionally divided again. The division, however, does not ensue into two parallel resonators that are independent of one another but in the form of a three-port configuration. The input 4 of both parallel resonators is composed of a shared terminal strip 28-4 at which the interdigital fingers to be excited lie. The terminal strip of the output is divided into two bus bars 28-5 and 28-6, where each bus bar corresponds to the output of one of the two parallel resonators.

[00116] The parallel branch with the resonator R_{p1} together with one of the non-combined parallel resonators R_{p2} are already electrically connected to one another on the chip at the ground output 28-2. A connection to the housing only ensues subsequently in the fabrication. The remaining parallel branch with the parallel resonator R_{p3} is connected to the housing independently. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Fig. 29. It is basically comparable to the equivalent circuit diagram in Fig. 26. The inductance L_{ser1} corresponds to an inductance between the connection of the parallel resonators R_{p1} and R_{p2} on the chip and the housing ground pin outside; the inductance L_{ser2} corresponds to a further inductance between the non-coupled resonator R_{p3} and the housing ground pin outside.

[00117] The filter from Fig. 28 has a filter characteristic that does not differ from the filter from Fig. 26 and is therefore also characterized by curve 27-1 in Fig. 27. In contrast to

the embodiment 4, a different form of the division of a parallel resonator is shown, which differs essentially in the layout but not in the effect on the selection behavior.

[00118] Fig. 31 shows portions of an inventive filter structure as a schematic plan view onto a substrate. The resonators R are shown as interdigital transducers. The two coupled resonators R_{p1} and R_{p2} in the parallel branch are electrically connected to one another on the substrate and comprise a shared ground connection 31-1 that is connected to a ground terminal pad 31-3 by a bond wire 31-2, which represents one part of the inductance L_{ser} . The connection on the substrate is realized here with a stripline but can also comprise a bond wire. Even though only two coupled resonators are shown here, the invention also covers filters having more than two coupled resonators.

SIXTH EMBODIMENT

[00119] The description of a sixth embodiment (Embodiment 6) of the present invention is shown in Fig. 30, which uses a SAW filter of the reactance filter type having at least two parallel branches. In at least two of all existing parallel branches R2 and R3, the output sides (30-3 and 30-4) of the parallel resonators are electrically connected to one another electrically on the chip. The connection 30-5 to the housing only ensues subsequently in the fabrication. The remaining parallel branches are connected to the housing independently. The connection of the chip (30-1) to the housing is not implemented as described previously (as a bond connection) but is produced with a bump connection (30-5).

[00120] The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is not different compared to the general exemplary embodiment and shown in Fig. 13. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside. For bump technology structuring, the value for the inductance L_{ser} is greatly reduced compared to an embodiment with bond wire since the bond connection itself has its nearly no inductance in contrast to a bond connection. Only the inductive part of the stripline on the chip and the housing lead-through inductance up to the external housing ground pin remain.

[00121] Fundamentally, all of the exemplary embodiments discussed above (even though it is with more than four basic elements having at least two parallel branches at the output side already electrically connected on the chip) can be realized in conjunction with the bump technology. The filter characteristics are also fundamentally comparable; however, the

value that can be achieved for the serial inductance L_{ser} is lower. In order to achieve the required selections (for example, in the range of the LO suppression and/or image suppression) it is thus necessary to employ the inventive method for targeted variation of the stop band. The invention also offers the advantage of reducing the number of necessary ground bumps and, thus, the chip area for ground terminals. This results in an even further miniaturization of the overall SAW filter.

[00122] The above-described devices are illustrative of the principles of the present invention. Numerous modifications and adaptations will be readily apparent to those skilled in this art without departing from the spirit and scope of the present invention.

ABSTRACT

In a SAW filter of the reactance type having at least two SAW resonators in two parallel branches and a SAW resonator in a serial branch, the invention provides that an electrical connection fashioned on the substrate of the ground sides of the two SAW resonators in the parallel branches is done before the bonding to the housing in order to achieve a shift of the pole point belonging to the parallel branch to a lower frequency.

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SPECIFICATION

TITLE

SAW FILTER OF THE REACTANCE FILTER TYPE WITH IMPROVED STOP BAND SUPPRESSION AND METHOD FOR OPTIMIZING THE STOP BAND SUPPRESSION

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] The present invention is directed to a surface-active wave filter (SAW) and, specifically, to a SAW filter of the reactance filter type with improved stop band suppression as well as to a method for the optimization of the stop band suppression.

DESCRIPTION OF THE RELATED ART

[0002] Reactance filters are known from classical filter technology. When SAW resonators are employed for the individual resonators instead of discrete elements [~~inductances~~](**inductors** and capacitors), then this is called a SAW filter according to the reactance filter type.

[0003] Given SAW filters of the reactance filter type, SAW resonators are employed as impedance elements. Figure 1 shows the schematic structure of a known resonator. It comprises metallic structures on the surface of a piezo-electric substrate and has a terminal pair 1-1 and 1-2 to which an interdigital transducer 1-4 is connected for the transformation of electrical energy into acoustic energy. A reflector 1-3 and 1-5 is respectively arranged at both sides of the interdigital transducer 1-4 along the acoustic axis in order to prevent the acoustic energy from escaping.

[At]**[0004]** **Figure 2, on** the left, [Figure 2] shows the equivalent circuit diagram for a SAW resonator R and shows the symbol employed for the resonator at the right. A series resonant circuit composed of dynamic inductance L_1 , dynamic capacitor C_1 and dynamic

resistor R_1 (when taking losses into consideration) is located in the first branch of the parallel circuit, and the static capacitor C_0 of the interdigital transducer is located in the second branch. The series resonant circuit reflects the behavior of the resonator in the resonance case, i.e., in the range of the resonant frequency f_r . The static capacitor reflects the behavior in the frequency ranges $f < f_r$ and $f > f_r$. The dynamic capacitor C_1 is proportional to the static capacitor C_0 of the interdigital transducer:

[0005] $C_1 \sim C_0$ (1.1)

[0006] A resonator has a resonant frequency f_r and an anti-resonant frequency f_a . The following applies to the resonant frequency f_r :

[0007]
$$f_r = \frac{1}{2\pi} \sqrt{L_1 * C_1} \quad (1.2)$$

[0008] The following applies for the anti-resonant frequency f_a of a resonator:

[0009]
$$f_a = f_r * \sqrt{1 + C_1 / C_0} \quad (1.3)$$

[0010] The basic unit of a SAW reactance filter is ~~{what is referred to as a basic element}~~ **a “basic element”** as shown in Figure 3. It is composed of a first resonator R_1 with resonant frequency f_{rp} and appertaining anti-resonant frequency f_{ap} in the parallel branch and of a second resonator R_2 with resonant frequency f_{rs} and appertaining anti-resonant frequency f_{as} in the serial branch. The frequency curve of the admittance Y_p of the resonator R_1 in the parallel branch and the frequency curve of the impedance Z_s of the resonator R_2 in the serial branch are shown in Figure 4. For producing a band-pass filter with the middle frequency f_0 , the resonant frequencies of the two resonators have the following relationship:

[0011] $f_{ap} \approx f_{rs} \approx f_0$ (1.4)

[0012] Each basic element is ~~{to be}~~ fundamentally viewed as **a two-port element** with the terminals 3-1 or ~~{, respectively,}~~ 3-2 of port 1 and the terminals 3-3 or ~~{, respectively,}~~ 3-4 of port 2 (see Figure 3). At the same time, the ~~{terminals}~~ **terminal** 3-1 is the input and the terminal 3-3 is the output of the series resonator. The input of the parallel resonator is connected to the terminal 3-1. The terminals 3-2 and 3-4 represent the reference ground ~~{given}~~ **for** an asymmetrical operation. The output 3-~~{5}~~ **4** of the parallel resonator that faces toward the reference ground is referred ~~{to}~~ below as **the** output side or ~~{, respectively,}~~ ground side of the parallel resonator. The inductance L_{ser} that lies between the output side of

the parallel resonator and the reference ground reflects the connection to the housing ground in the real structure.

[0013] The selection level of the SAW filter according to the reactance filter type is defined, first, by the relationship C_{0p}/C_{0s} of static capacitor C_{0p} in the parallel branch and static capacitor C_{0s} in the series branch and is defined, second, by the ~~{plurality}~~ **number** of basic elements connected following one another ~~{(cascaded)}~~.

~~{(in a cascaded manner, i.e., in series)}~~.

[0014] The basic elements ~~{in the case of a cascading}~~ **when they are connected in series** are usually ~~{(circuit)}~~ **circuit**-adapted, i.e., **they are** respectively mirrored. Figure 5 and Figure 6 show two examples of a reactance filter ~~{wherein}~~ **in which** respectively two basic elements are cascaded. The output impedance 5-1 (Z_{out}) or~~[-, respectively,]~~ 6-1 (Z_{in}) of the first basic element is equal to the input impedance 5-2 or~~[-, respectively,]~~ 6-2 of the second basic element, ~~{as a result whereof the}~~ **resulting in a minimization of** losses due to mismatching ~~{are minimal}~~. Many structures are possible or known for reactance filters with respect to the ~~{plurality}~~ **number** and arrangement of the basic elements.

[0015] Resonators of the same type (series resonator or parallel resonator) lying immediately behind one another can also be respectively combined to form one~~[-, whereby]~~ **in which** the ~~{capacitive}~~ overall ~~{effect}~~ **capacitance** remains the same. The interconnection of a filter according to Figure 7 corresponds in effect to that of a filter according to Figure 8.

[0016] Figures 9 and 10 show the typical, actual structure of a SAW filter on a piezoelectric substrate 9-1 in a ceramic housing 9-0 and the typical connecting technique with bond wires 9-8 through 9-12 or~~[-, respectively,]~~ 10-9.

[0017] At the output side 9-15 through 9-17, the parallel resonators R1, R3 and R5 are connected to the housing ground pads 9-4, 9-5 and 9-7 via bond wires 9-9, 9-10 and 9-12.

[0018] As a result of the typical structuring technique (see Figure 9 and Figure 10), series inductances between, for example, the output side 9-17 of the parallel resonator R5 on the substrate (chip) 9-1 and the ground 10-5 ~~{adjacent at}~~ **next to** the outer housing pin 9-4 are obtained given the connection of the parallel branches to ground. These essentially include the inductive part of the stripline on the chip, the inductance of the bond connection 9-9 and that of the housing lead-through 10-3.

[0019] These series inductances influence the behavior of the filter both in the passband as well as in the stop band. $f < f_0$ applies for the pass band. The resonant frequency and, thus, the bandwidth of a resonator can, as known, be modified by an external wiring belonging to the resonator. An inductance serially with the resonator increases the effective dynamic inductance, ~~[as a result whereof]~~ **resulting in a drop in** the resonant frequency f_r ~~[drops]~~. Since the anti-resonant frequency f_a is shifted to only a very slight extent, the bandwidth $\Delta f = f_a - f_r$ of a resonator is increased with the serial inductance. The bandwidth of the SAW filter is also increased in the case of a parallel resonator.

[0020] $f < f_0$ and $f > f_0$ applies for the stop band. Here, the equivalent circuit diagram of a resonator is reduced to its static capacitance C_0 since the series resonant circuit is extremely high-impedance beyond f_0 and corresponds to a no-load **condition**. An inductance L_{ser} **connected** serially with the resonator ~~[yields a]~~ **produces the** series resonant circuit shown in Figure ~~[11]~~ **11b** having a resonant frequency

[0021]
$$f_{pol} = 1/2\pi \sqrt{L_{ser} * C_0} \quad (1.5)$$

[0022] In the case of an inductance **connected** serially with a parallel resonator, this means that the energy of the filter can flow off directly to ground given the frequency f_{pol} ; ~~[what is referred to as a pole point]~~ **a "pole point"** thus forms in the filter curve, i.e., an increased suppression in the stop band. A plurality of pole points in the stop band corresponds to the plurality of parallel branches with series inductance. Pole points f_{pol1} and f_{pol2} that can be distinguished from one another in terms of frequency derive only given different products $\Pi_1 = L_{ser1} * C_{01}$ and $\Pi_2 = L_{ser2} * C_{02}$. When the products are identical, then the pole points lie at the same frequency; a double pole point $f_{pol} = f_{pol1} = f_{pol2}$ is obtained with a higher suppression than ~~[given]~~ **that of** a simple **single** pole point.

[0023] Figure ~~[11a]~~ **11b** shows the attenuation behavior of a resonator in the parallel branch to which an inductance L_{ser} is serially connected at the output side of the parallel resonator. As in Figure 11b, the series resonant circuit of the resonator (whose resonant frequency $f_p = f_0$) was removed in order to illustrate the pole point. What typically applies for the frequency of the pole point f_{pol} is $f_{pol} > f_0$, ~~[whereby]~~ **where** f_0 is equal to the resonant frequency of the filter. A high attenuation is then obtained for the pole point.

[0024] SAW filters of the reactance filter type are mainly employed as RF filters in the mobile radio telephone field since they exhibit extremely low losses in the pass band. As **an** RF filter in the mobile radio telephone field, the SAW filter of the reactance filter type

must, over and above this, suppress~~[,]~~; first, the duplex band (i.e., the reception band given a transmission filter and, conversely, the transmission band given a reception filter); and, second, ~~[must suppress]~~ the signal at the local oscillator frequency (LO) and/or at the image frequency in order to prevent unwanted mixed products in the telephone.

[0025] The local oscillator lies above or below the middle ~~[frequencies]~~ **frequency** f_0 of the filter. The distance from the middle frequency f_0 corresponds to the intermediate frequency (ZF) employed for the signal editing. The image frequency has the spacing $2 \cdot ZF$ from the middle frequency f_0 . Since momentary ZF frequencies in the range of 100-400 MHz are employed, the SAW filter - ~~[dependent]~~ **depending** on the application - must comprise good attenuation properties of, typically, more than 30 dB in the range $f_0 \pm$ ~~[plus/minus]~~ 100-800 MHz. In the most frequent instances, the local oscillator lies above the middle frequency f_0 .

[0026] There are various possibilities for achieving an adequate attenuation in the range of the LO frequency and/or image frequency. ~~[Possibly A is comprised therein that]~~ **According to a first possibility**, the general selection level **may** be made correspondingly high (the minimum attenuation below the pass band given approximately $f_0/2$ is valid as **a** criterion for this). The great disadvantage **in this situation** is, however, that the losses in the pass band also increase with **an** increasing selection level. This is unacceptable for the signal processing in the telephone in most cases.

[0027] The second possibility ~~[B derives from the aforementioned]~~ **is based on the previously mentioned** fact that an inductance present ~~[given]~~ **for** the traditional structuring technique generates a pole point serially with a parallel resonator that lies exactly at the LO or image frequency. Given the great spectrum of ZF frequencies employed, a possibility must be established in this case in order to vary the generated pole point over a range of approximately 700 MHz.

[0028] Since the static capacitance C_{0p} in the parallel branch is the determining factor for the filter performance (passband, matching and selection level), ~~[it]~~ **the pole point** can only be varied to an extremely slight degree with given filter demands such that the position of pole points in the stop band also simultaneously changes.

[0029] Likewise, the degree of freedom for the size of the inductance serially between output side of the parallel resonator and ground is limited. ~~[Due]~~ **The inductive part of the stripline on the chip can be varied to only a limited extent, due** to the necessity for

miniaturization as well as for cost reasons, the chips that are employed are becoming smaller and smaller~~[, this resulting therein that the inductive part of the stripline on the chip can be varied to only a limited extent]~~. The length and the inductance of the associated bond connection ~~[correlating therewith]~~ can likewise hardly be varied any more with any housing in the course of the progressing trend towards miniaturization. Moreover, the inductance that derives from the housing lead-through is fixed for a given housing.

~~[The]~~[0030] This second possibility ~~[B]~~ is thus also not established anymore to an adequate extent for SAW filters according to the reactance filter type in housings that have been miniaturized further~~[, namely it]~~. This possibility is no longer established to an adequate degree in order to assure the LO and/or image suppression ~~[by means of]~~ via suitably placed pole points over a great frequency range from f_0 plus 100-800 MHz.

~~[Particularly given the future connection technology of "flip-chip-technique" wherein bump connections are employed instead of the bond wires, it]~~[0031] It is impossible to generate pole points at relatively low frequencies~~[, i.e.]~~ (i.e., in the range of 100 MHz above the middle frequency f_0), particularly given the future connection technology of "flip-chip-technique" in which bump connections are employed instead of the bond wires, since the inductances present given this structuring technique serially to the output side of a parallel resonator are too small (see Equation 1.5), and the static capacitances of the parallel branches can likewise not be selected great enough because of the required self-matching to 50Ω .

SUMMARY OF THE INVENTION

[0032] It is therefore an object of the present invention to ~~[specify]~~ provide a way of ~~[how]~~ designing a filter ~~[can be designed]~~ such that an improved stop band suppression can be obtained for specific LO frequencies and image frequencies over a possible range from 100 through 800 MHz next to the middle frequency. In particular, a way ~~[should be specified]~~ is provided for shifting pole points of a reactance filter into a desired region close to the middle frequency f_0 without greatly influencing the remaining filter behavior.

[0033] This object is ~~[inventively]~~ achieved by a surface-active wave (SAW) filter of a reactance filter type, comprising a first SAW resonator in a parallel branch of the filter that has a static capacitance; a further first SAW resonator in a further parallel branch of the filter that has a static capacitance; a second SAW resonator in a serial branch of the filter that has a static capacitance; at least one basic element fashioned on

a piezoelectric substrate, the basic element comprising the first SAW resonator and the second SAW resonator; an electrical connection of ground ~~{with a filter according to claim 1. Advantageous developments in a method for shifting pole points may be derived from further claims.}~~

~~As a result of a connection of the ground-side output~~ sides of the ~~{parallel branches respectively comprising a resonator on the chip, a}~~ first SAW resonator and of the further first SAW resonator (collectively, two first resonators), the electrical connection of the ground sides configured to be made before bonding to a housing that contains the filter; and a bump connection on a housing link of the two electrically connected ground sides of the two first resonators; wherein at least the static capacitance of the first SAW resonator and the static capacitance of the further first saw resonator differ from one another.

[0034] This object is also achieved by a method for operating this SAW filter, comprising shifting a pole point in the SAW filter; raising or lowering the static capacitance of at least one of the first SAW resonator and the further first SAW resonator; and raising or lowering a static capacitance of one or more further, non-coupled first resonators such that an overall sum of the static capacitances of all parallel resonators remains identical.

[0035] A coupling of the parallel branches is inventively produced~~{,}~~ as a result ~~{whereof the }~~ of a connection of the ground-side output sides of the parallel branches respectively comprising a resonator on the chip. This permits a greatly modifiable frequency ~~{position}~~ positioning of the appertaining pole point (also referred to as "coupled pole point" below) ~~{can be modified to a great extent. }~~.

[0036] As a result ~~{thereof}~~, it is possible to produce a SAW filter that comprises pole points at lower frequencies than could be achieved by the previous, serial interconnection of the parallel branches with existing, structure-conditioned inductances according to Equation (1.5). It is also possible to shift one or more pole points in a given filter over a broader frequency range than was ~~{hitherto}~~ previously possible in a given filter. With the invention, thus, a pole point can be generated at exactly ~~{at}~~ the frequency at which a high selection is required, for example, at an arbitrary LO or image frequency.

[0037] Such demands for the suppression of signals at the local oscillator frequency (LO suppression) and/or at the image frequency (image suppression) can thus still be satisfied

in extremely small housings having very low structure-conditioned inductances. One or more pole points can be shifted to a desired frequency given an established bond inductance, conduct inductance or housing lead-through inductance without this requiring an increase in the serial inductance. Additionally, of course, the serial inductance can also be increased.

[0038] Moreover, the plurality of ground connections that are offered can be set independently of the plurality of parallel branches employed, this leading to a lower space requirement. It is precisely in view of new connecting technologies (bump connections instead of bond connections) and new housing technologies that the embodiments according to the invention represent the sole possibility for achieving the ~~{aforementioned}~~ **previously mentioned** selection demands in miniaturized housings.

[0039] The principle for shifting the pole points according to the present invention ~~{shall be}~~ **is** explained in greater detail below on the basis of exemplary embodiments and the appertaining figures. The following, concrete embodiments are examples of the employment in a SAW filter of the reactance filter type.

[THEREBY SHOWN ARE:] DESCRIPTION OF THE DRAWINGS

- ~~[Fig. 1]~~ **Fig. 1** **is a pictorial diagram of** a one-port SAW resonator;
- Fig. 2 **is** the equivalent circuit diagram and symbol for a SAW resonator;
- Fig. 3 **is a schematic diagram showing** a basic element of a SAW filter of the reactance filter type;
- Fig. 4 **is a graph illustrating the** interaction of parallel and series resonators;
- Fig. 5 **is a schematic diagram showing a** cascade of two basic elements;
- Fig. 6 **is a schematic diagram showing a** cascade of two basic elements ;
- Fig. 7 **is a schematic** diagram of a reactance filter;
- Fig. 8 **is a schematic** diagram of a reactance filter with the reduced structure s-p-s-p;
- Fig. 9 **is a plan view** ~~{ontø}~~ **of** a SAW filter ~~{in}~~ **into** the housing without cover;
- Fig. 10 **is a cross-section view** through a SAW filter in the housing;
- Fig. 11a **is a graph illustrating the** pole point;
- Fig. 11b **is an** equivalent circuit diagram for the attenuation behavior of a parallel branch;
- Fig. 12 **is an** equivalent circuit diagram of ~~{a}~~ **an inventive** filter;
- Fig. 13 **is an** equivalent circuit diagram for the attenuation behavior of a SAW filter;
- Fig. 14 ~~{diagram that shows}~~ **is a graph showing** the relationship between ΔL_{ser} and **the** pole point;

- Fig. 15 **is a graph showing the** dependency of the frequency position of the pole point on the static capacitance;
- Fig. 16 **is a schematic diagram of a first embodiment of a** filter having three basic elements;
- Fig. 17 **[the] is an** equivalent circuit diagram **[thereof] of the first embodiment circuit shown in Fig. 16** in the stop band;
- Fig. 18 **is a graph illustrating** the attenuation behavior **[thereof] of the first embodiment circuit shown in Fig. 16;**
- Fig. 19 **is a schematic diagram of a second embodiment of a** filter with four basic elements;
- Fig. 20 **[the] is an** equivalent circuit diagram **[thereof] of the second embodiment circuit shown in Fig. 19** in the stop band;
- Fig. 21 **is a graph illustrating** the attenuation behavior **[thereof] of the second embodiment circuit shown in Fig. 19;**
- Fig. 22 **is a schematic diagram of a third alternative embodiment of a** filter with four basic elements;
- Fig. 23 **[the] is an** equivalent circuit diagram **[thereof] of the third embodiment circuit shown in Fig. 22** in the stop band;
- Fig. 24 **is a graph illustrating** the attenuation behavior **[thereof] of the third embodiment circuit shown in Fig. 22;**
- Fig. 25 **is a schematic diagram of a fourth embodiment alternative embodiment of a** filter with four basic elements;
- Fig. 26 **[the] is an** equivalent circuit diagram **[thereof] of the fourth embodiment circuit shown in Fig. 25** in the stop band;
- Fig. 27 **is a graph illustrating** the filter characteristic **[thereof] of the fourth embodiment circuit shown in Fig. 25;**
- Fig. 28 **is a schematic diagram of a fifth alternative embodiment of a** filter with four basic elements;
- Fig. 29 **[the] is an** equivalent circuit diagram **[thereof] of the fifth embodiment circuit shown in Fig. 28** in the stop band;
- Fig. 30 **is a plan view of the** filter structure **in a sixth embodiment** with **a** bump connection; **and**
- Fig. 31 **is a plan view of the** filter structure with **a** bond connection.

DETAILED DESCRIPTION OF THE INVENTION

[0040] Fig. 12 shows a simple filter structure of the invention symbolically as [a] an equivalent circuit diagram, ~~[this being potentially]~~ **which may be** part of a larger filter structure with further basic elements. ~~[Given]~~ **For a filter circuit having** (at least) two of the parallel branches with the parallel resonators R2 and R3, the output sides 12-6 and 12-7 are already inventively electrically connected to one another on the chip **itself** (substrate) 12-8. Only ~~[thereafter does]~~ **after such a connection is present does one make** a connection to the housing ground pad 12-4 comprising, for example, a bond connection 12-5~~[, ensue]~~.

1.

[0041] Fig. 13 shows the equivalent circuit diagram for the frequency range $f \ll f_0$ and $f \gg f_0$ ~~[wherein]~~ **where** only the static capacitance C_0 takes effect for each resonator. The selection behavior of a SAW filter according to the reactance filter type can be largely described with this reduced equivalent circuit diagram. The inductance L_{ser} corresponds to the inductance between the connection of the parallel resonators on the chip and the housing ground pin (equals terminal for ground at the housing) outside.

~~[A]~~[0042] **The** coupling of the two parallel branches already electrically connected on the chip **that** occurs~~[, This]~~ leads to a frequency position change of the pole points in the stop band. The frequency position of the coupled pole point can be identified **based** on ~~[the basis of]~~ the equivalent circuit diagram from Figure 13~~[,]~~ which shows a two port **circuit** Z. The two port **circuit** Z ~~[then]~~ comprises a pole point when the impedance to ground becomes zero.

[0043] $Z_{21} = 0$

[0044] **where** Z_{21} is ~~[thereby]~~ a systematically referenced matrix element from the impedance matrix. For determining Z_{21} , the two port **circuit** Z can be divided into a series circuit of the two-ports Z' and Z". The two-port Z' comprises the Π -circuit composed of the three capacitors C_{op1} , C_{op2} and C_{os} . The two-port Z" comprises only the inductance L_{ser} . The following thus derives:

[0045]

$$Z'_{21} = \frac{1}{j\omega \left(C_{op2}C_{op1} + \frac{C_{op1}C_{op2}}{C_{os}} \right)} \quad (2.1)$$

[0046]

[0047] $Z''_{21} = j\omega L_{ser}$ (2.2)

[Whereby j=][0048] Where j represents the imaginary number and $\omega = 2\pi f$ applies.

[0049] With

[0050] $Z_{21} = Z'_{21} + Z''_{21}$ (2.3)

[0051] it follows that

[0052]

$$Z_{21} = \frac{1 - \omega^2 L_{ser} \left(C_{0p2} + C_{0p1} + \frac{C_{0p1} C_{0p2}}{C_{0s}} \right)}{j\omega \left(C_{0p2} + C_{0p1} + \frac{C_{0p1} C_{0p2}}{C_{0s}} \right)} \quad (2.4)$$

[0053]

[0054] When the numerator of the expression of (2.4) becomes zero,

[0055]

$$1 - \omega^2 L_{ser} \left(C_{0p2} + C_{0p1} + \frac{C_{0p1} C_{0p2}}{C_{0s}} \right) = 0 \quad (2.5)$$

[0056] Z_{21} becomes zero. The following ~~[is obtained therefrom]~~ derives for the frequency position of the coupled pole point:

[0057]

$$f_{pol} \text{ (coupled)} = \frac{1}{2\pi \sqrt{L_{ser} \left(C_{0p2} + C_{0p1} + \frac{C_{0p1} C_{0p2}}{C_{0s}} \right)}} \quad (2.6)$$

[0058]

[0059] It can be clearly seen compared to the pole points previously obtained without coupling of the parallel branches on the chip according to Equation (1.5).

(2.7)

[0060]
$$f_{pol2} = \frac{1}{2\pi} \sqrt{L_{ser} * C_{op2}} \quad (2.8)$$

[0061] That the additional capacitance parts $\frac{C_{op1}C_{op2}}{C_{os}}$ and C_{op2} or C_{op1} shift the coupled pole point to a far lower frequency given the same inductance L_{ser} .

[Numerical][0062] **To illustrate with a numerical** example: for a known SAW filter of the reactance filter type, the frequency f_{pol} of a pole point is calculated as:

[0063]
$$f_{pol1} = \frac{1}{2\pi} \sqrt{L_{ser} * C_{op1}} = \frac{1}{2\pi} \sqrt{1nH * 4pF} = 2.52 \text{ GHz}$$

[0064] Typical values of 1nH and 4pF ~~[were thereby]~~ **are** assumed **in this example** for the serial inductance L_{ser} and for the static capacitance C_{op} .

[0065] According to Equation 2.6 and given the same assumed values for L_{ser} and C_{op} and likewise given 4pF for C_{os} ,

[0066]

[0067]
$$f_{pol2} = \frac{1}{2\pi} \sqrt{1nH * (rpF + 4pF + (4pF)^2 / 4pF)} = 1.45 \text{ GHz}$$

[0068] derives when two parallel branches are coupled.

[0069] When a filter comprises a plurality of parallel branches, then a plurality of parallel branches can also be connected to one another at the ground side, these **are** also ~~[continuing to be]~~ referred to as "coupled parallel branches". The plurality and combination of the connected parallel branches plays a critical part for the frequency position of the coupled pole points and is ~~[to be taken into consideration]~~ **considered** in the selection of the filter structure for a desired frequency position of the pole points.

[0070] Fig. 14 indicates the dependency of the position of a coupled pole point on the size of the inductance L_{ser} . The two curves 14-1 and 14-2 indicate the filter behavior for the same filter, ~~[whereby]~~ **where** only L_{ser} has been differently selected. A different frequency position of the pole points derives dependent on L_{ser} , ~~[whereby]~~ **where** the inductance L_{ser1}

belonging to $f_{\text{pol } 1}$ is smaller than $L_{\text{ser } 2}$. The shift of the pole points toward lower frequencies is ~~[all the]~~ greater the higher the inductance L_{ser} is.

[0071] To a lesser extent, the frequency position of the pole point can be set by a variation of the product of static capacitances of the coupled parallel branches

[0072] $\Pi_p C = C_{\text{op}1} * C_{\text{op}2} \quad (2.9)$

[0073] So that the filter behavior in the passband and the general selection level is not modified, such a variation of the product of static capacitances in the parallel branch can be implemented only upon retention of their sum:

[0074] $\Sigma C_p = C_{\text{op}1} + C_{\text{op}2} = \text{constant} \quad (2.10)$

[0075] The following method can be applied: the static capacitance $C_{\text{op}1}$ of the first couple parallel resonator is increased by the same amount C_{const}

[0076] $C_{\text{op}1(\text{new})} = C_{\text{op}1} + C_{\text{const}} \quad (2.11)$

[0077] by which the static capacitance $C_{\text{op}2}$ of the second couple parallel resonator is lowered:

[0078] $C_{\text{op}2(\text{new})} = C_{\text{op}2} - C_{\text{const}} \quad \text{with } C_{\text{const}} < C_{\text{op}2}, \quad (2.12)$

[0079] so that the product ΣC_p in fact changes but the sum of the static capacitances remains identical.

[0080] $\Sigma C_p = C_{\text{op}1(\text{new})} + C_{\text{op}2(\text{new})} = C_{\text{op}1} + C_{\text{op}2} = \text{constant} \quad (2.13)$

[0081] and no modifications of the passband or of the general selection level need be accepted.

[0082] When a greater frequency offset of the couple pole point is necessary, the participating static capacitances $C_{\text{op}1}$, $C_{\text{op}2}$ or C_{os} can be varied. When more parallel resonators than the two parallel resonators to be coupled are present, then the sum $C_{\text{op}1} + C_{\text{op}2}$ can be raised (or lowered), and the static capacitance of a non-coupled parallel resonator can be lowered (or raised) for balancing such that the total sum of all static capacitances remains the same in the parallel branches~~[The]~~, thus retaining the general selection level ~~[is retained as a result thereof]~~.

1.

[0083] Fig. 15 shows how, given a constant inductance L_{ser} , the frequency of the couple pole point is increased as a result of a reduction of the sum of the static capacitances $C_{op1} + C_{op2}$ of the coupled parallel branches~~[-]~~ being increased by the factor 1.2. For balancing, the static capacitance of a further parallel branch ~~{was}~~ **is** correspondingly increased.

[0084] Another possibility for shifting the couple pole point is ~~{comprised in}~~ **to** intentionally ~~{splitting}~~ **split** a parallel resonator P into two individual resonators P' and P'' parallel to one another, ~~{whereby}~~ **where** the sum of the capacitances of the split, individual resonators is equal to the original capacitances C_{op} :

[0085]
$$C_{op} = C'_{op} + C''_{op}$$

[0086] When one of these parallel resonators P' is coupled with a further parallel resonator, but not with the parallel resonator P'', then the frequency position of the coupled

pole point can be set on the ~~{base is}~~ **basis** of the division ratio $\frac{C'_{op}}{C''_{op}}$ of the static capacitance of the split parallel resonators P' and P'', since C'_{op} influences the frequency position of the coupled pole point.

[0087] A single series resonator or a plurality of series resonators can be arranged between coupled parallel branches. Since the size of the static capacitance C_{os} that lies between the coupled parallel resonators influences the frequency position of the coupled pole point according to Equation 2.6, the frequency position of the coupled pole point can likewise be shifted with the following method.

[0088] When further series resonators S_n **are present**, in addition to the series resonator or resonators S lying between the coupled parallel branches ~~{are present}~~, then the static capacitance C_{os} ~~{thereof}~~ can be raised (or lowered) ~~{and}~~. **Additionally**, for balancing, the static capacitance of the series resonators S_n that do not lie between the coupled parallel resonators can be lowered (or raised) such that the total sum of all static capacitances in the series branches remains the same. ~~{As a result thereof,}~~ **This results in retaining** the general selection level ~~{is retained and}~~ **and modifying** the frequency position of the coupled pole point ~~{is modified}~~.

~~{As already explained, the}~~ **[0089]** **The** range for the variation of the static capacitances C_p in the parallel branch and of the serial inductances L_{ser} (between the connection of the parallel

branch on the chip and the outside terminal at the housing) is limited. The same is therefore also true for the frequency range in which the pole points can be displaced. In contrast to the measures known from the prior art, however, the range of variation achieved according to the invention enables the manufacture of SAW filters - even given extremely miniaturized housings - with ~~a~~ an LO suppression and image suppression that is required for the employment as an RF filter in the mobile radio telephone field.

[0090] Concrete embodiments of inventive filters ~~{are now recited}~~ described below.

FIRST EMBODIMENT

~~{1 (also see Fig. 16 through Fig. 18):~~

A-][0091] A first embodiment (Embodiment 1) of the invention, illustrated in Figs. 16-18, uses a structure having three basic elements ~~{is employed}~~. A first basic element is connected ~~{such}~~ to the input port 16-1 such that both the parallel branch as well as the series branch comprise a connection to the input port. The second basic element is connected according to the matching demand $Z_{out} = Z_{in}$. The third basic element follows in the same way. Differing from the case at the input port, only one series branch is thus directly connected to the output port. A sequence $p-s - s-p - p-s$ for the resonators ~~{derives}~~ is present from the input to the output, ~~{whereby}~~ where p stands for parallel resonator and s stands for series resonator. Fundamentally, the input port and output port can be interchanged without modifying the filter properties, ~~{whereby}~~ from which the sequence presented is $s-p - p-s - s-p$ ~~{derives}~~.

~~{:~~

[0092] As is known in the art, identical resonators can also be combined upon retention of their ~~{capacitative effect}~~ capacitance. The following structures with a minimum number of resonators thus derive:

[0093] $p-s-p-s$ or ~~{, respectively,}~~ $s-p-s-p$

[0094] however, mixed forms having partial combination of the resonators area also possible:

[0095] $p-s-p-p-s$ or ~~{, respectively,}~~ $s-p-p-s-p$

[0096] $p-s-s-p-s$ or ~~{, respectively,}~~ $s-p-s-s-p$

[0097] For the sake of simplicity, the embodiments below are only explained on the basis of a minimum of resonators and without additional indication of the interchangeability of the input port and the output port, and are shown this way in the Figures. Nonetheless, the invention also comprises modifications according to the ~~{example that has just been explained above.~~

~~{above example.~~

[0098] Fig. 16 symbolically shows the structure of ~~{embodiment}~~ **Embodiment 1**. The two parallel branches are already electrically connected to one another on the chip and a connection to the housing only ensues subsequently in the fabrication. The equivalent circuit diagram for the selection behavior in the range $f < f_0$ and $f > f_0$ is shown in Fig. 17. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside.

[0099] The filter has a filter characteristic as identified by curve 18-1 in Fig. 18. The comparison to filter curve 18-2 (corresponding to the filter shown in Fig. 8) ~~{wherein}~~ in which the parallel branches on the chip are not connected to one another, clearly shows how the frequency position of the pole points in the stop band with a typical inductance $L_{ser} = 1.0$ nH is shifted by the connection of the parallel branches on the chip. The selection is increased by more than 10 dB in the frequency range between the vertical lines (typical frequency range for LO suppression and image suppression given low intermediate frequency).

SECOND EMBODIMENT

~~{2 (also see Fig. 19—Fig. 21):~~

~~{[00100]~~ A second embodiment (Embodiment 2) is illustrated in Figs. 19-21. Fig. 19 symbolically shows the structure of ~~{a}~~ the second inventive embodiment ~~{wherein}~~ in which a structure having four basic elements is employed. A first basic element is connected ~~{such}~~ to the input port 19-1 such that both the parallel branch as well as the series branch comprise a connection to the input port. The second basic element is connected according to the matching requirement $Z_{out} = Z_{in}$. Basic element 3 ~~{and}~~, 4 ~~{follow}~~ follows in the same way. Just as at the input port, both a parallel branch as well as a series branch are ~~{thus}~~ directly connected to the output port 19-3. A sequence for the resonators from the input to the output derives as follows:

[00101] *p-s-p-s-p*

~~{whereby}~~**[00102]** where *p* stands for parallel resonator and *s* stands for series resonator. Resonators of the same type are already combined.

[00103] Two of the three parallel branches are already electrically connected to one another on the chip and a connection to the housing only ~~{ensues}~~ occurs subsequently via the inductance L_{ser2} . The remaining parallel branch is connected to the housing independently ~~{thereof}~~ via the inductance L_{ser1} . The equivalent circuit diagram for the selection behavior in the range $f < f_0$ and $f > f_0$ is shown in Fig. 20. The inductance L_{ser2} corresponds to an inductance between the connection 19-4 of the parallel resonators on the chip (shown with the broken line in ~~{the Fig.}~~ **Fig. 19**) and the housing ground pin outside.

[00104] In Fig. 21, the curve 21-1 shows the filter characteristic of the filter from Fig. 19. The comparison with the filter curve 21-2 ~~{wherein}~~ in which the parallel branches are not connected on the chip clearly shows how the frequency position of the pole points in the stop band, given a typical inductance $L_{ser2} = 1.0nH$, is shifted ~~{toward}~~ towards lower frequencies due to the connection of two of the three parallel branches on the chip ~~{here}~~. The selection is increased by approximately 10 dB in the frequency range between the vertical lines ~~{(the typical frequency range for LO suppression and image suppression at a low intermediate frequency)}~~.

THIRD EMBODIMENT

~~{3 (also see Fig. 22—Fig. 24):}~~

[00105] A third embodiment (Embodiment 3) is illustrated in Figs. 22-24. Fig. 22 symbolically shows the structure of the inventive ~~{embodiment 3. A}~~ Embodiment 3 in which a structure having three basic elements is employed. A first basic element is connected ~~{such}~~ to the input port 22-1 such that only the series branch comprises a connection to the input port. The second basic element is connected according to the matching requirement $Z_{out} = Z_{in}$. Basic element 3 ~~{and}~~, 4 ~~{follow}~~ follows in the same way. Just as at the input port, only one series branch is thus directly connected to the output port 22-3. A sequence for the resonators from the input to the output ~~{derives}~~ is as follows:

[00106] *s-p-s-p-s*

[00107] where *p* stands for parallel resonator *s* stands for series resonator.
Resonators of the same type are already combined.

~~[00108] [whereby p stands for parallel resonator s stands for series resonator. Resonators of the same type are already combined.]~~ The two parallel branches are already electrically connected to one another on the chip and a connection to the housing only ~~[ensues]~~ occurs subsequently. The equivalent circuit diagram for the selection behavior in the range $f < f_0$ and $f > f_0$ is shown in Fig. 23. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside. The filter from 22 has a filter characteristic as identified by curve 24-1 in Fig. 24. The comparison to the filter curve 24-2, ~~[whereby]~~ where the parallel branches are not connected on the chip, ~~[it]~~ clearly shows how the frequency position of the pole points in the stop band given a typical inductance $L_{ser} = 1.0 \text{ nH}$ is shifted due to the connection of the two parallel branches on the chip. The selection is increased by more than 8 dB in the frequency range between the vertical lines ~~[the]~~ (the) typical frequency range for LO suppression and image suppression at a high intermediate frequency).

FOURTH EMBODIMENT

~~[4 (also see Fig. 25 Fig. 27):~~

~~Fig. 25 symbolically shows the structure of the inventive]~~[00109] A fourth embodiment ~~[4. A]~~(Embodiment 4) is illustrated in Figs. 25-27 in which a structure and four basic elements ~~[is]~~ and employed. A first basic element is connected ~~[such]~~ to the input port 25-1 such that only the series branch having the resonator R_{S1} comprises a connection to the input port. The second basic element is connected in a mirrored fashion because of the matching demand $Z_{out} = Z_{in}$. Basic element 3 ~~[and]~~, 4 ~~[follow]~~ follows in the same way. Just as at the input port, only one series branch is thus directly connected to the output port 25-3. A sequence for the resonators from input to output ~~[derives]~~ is as follows:

[00110] *s-p-s-p-s*

[00111] Resonators of the same type are already combined; in contrast to ~~[the embodiment]~~ Embodiment 3, however, one parallel branch has been intentionally divided again. The division ensues such that each parallel resonator R_{p2} , R_{p3} forms its own two-port with its own electrical inputs and outputs. The combined parallel branch having the resonator R_{p1} together with one of the non-combined, two parallel branches (R_{p2}) are already electrically connected to one another on the chip at ~~[25]~~ 25-2, and a connection to the housing only ensues subsequently in the fabrication via L_{ser1} . The remaining parallel branch (R_{p3}) is connected to the housing independently ~~[thereof]~~. The equivalent circuit diagram for

the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Figure 26. The inductance L_{ser1} corresponds to an inductance between the connection of the parallel resonators R_{p1} and R_{p2} on the chip and the housing ground pin outside; the inductance L_{ser2} corresponds to an inductance between the parallel resonator R_{p3} on the chip and the housing ground pin outside.

[00112] The filter from Fig. 25 has a filter characteristic that is characterized by curve 27-1 in Fig. 27. The comparison to the filter curve 27-2, ~~{wherein}~~ **in which** the output sides of the parallel branches are not connected on the chip, clearly shows how the frequency position of the pole points in the stop band given a typical inductance $L_{ser1} = 1.0$ nH is shifted due to the connection of two of the three parallel branches on the chip. The selection is increased generally by more than 5 dB in the frequency range between the vertical lines ~~{(the typical frequency range for LO suppression and image suppression given a high intermediate frequency)}~~. The selection gain is far more than 10 dB when either a high LO suppression or image suppression is demanded.

FIFTH EMBODIMENT

~~{5 (also see Fig. 28 Fig. 30):~~

[00113] **A fifth embodiment (Embodiment 5) of the invention is illustrated in Figs. 28-30.** Fig. 28 symbolically shows the structure of the inventive ~~{embodiment 5-A}~~ **Embodiment 5 in which** a structure having four basic elements is employed. A first basic element is connected ~~{such}~~ to the input port 28-1 **such** that only the series branch comprises a connection to the input port. The second basic element is connected according to the matching demand $Z_{out} = Z_{in}$. Basic element 3 ~~{and}~~, 4 ~~{following}~~ **follows** in the same way. Just as at the input port, only one series branch is ~~{thus}~~ directly connected to the output port 28-3. A sequence for the resonators from input to output derives as follows:

[00114] *s-p-s-p-p-s*

[00115] Resonators of the same type are already combined similar to embodiment 4; however, one parallel branch is intentionally divided again. The division, however, does not ensue into two parallel resonators that are independent of one another but in the form of a three-port **configuration**. The input 4 **of** both parallel resonators is composed of a shared terminal strip 28-4 at which the interdigital fingers to be excited lie. The terminal strip of the output is divided into two bus bars 28-5 and 28-6, ~~{whereby}~~ **where** each bus bar corresponds to the output of one of the two parallel resonators.

[00116] The parallel branch with the resonator R_{p1} together with one of the non-combined parallel resonators R_{p2} are already electrically connected to one another on the chip at the ground output 28-2. A connection to the housing only ensues subsequently in the fabrication. The remaining parallel branch with the parallel resonator R_{p3} is connected to the housing independently ~~{thereof}~~. The equivalent circuit diagram for the selection behavior in the range $f < f_0$ and $f > f_0$ is shown in Fig. 29. It is basically comparable to the equivalent circuit diagram in Fig. 26. The inductance L_{ser1} corresponds to an inductance between the connection of the parallel resonators R_{p1} and R_{p2} on the chip and the housing ground pin outside; the inductance L_{ser2} corresponds to a further inductance between the non-coupled resonator R_{p3} and the housing ground pin outside.

[00117] The filter from Fig. 28 has a filter characteristic that does not differ from the filter from Fig. 26 and is therefore also characterized by curve 27-1 in Fig. 27. In contrast to the embodiment 4, a different form of the division of a parallel resonator is shown ~~{here, this differing}~~, which differs essentially in the layout but not in the effect on the selection behavior.

[00118] Fig. 31 shows portions of an inventive filter structure as a schematic plan view onto a substrate. The resonators R are shown as interdigital transducers. The two coupled resonators R_{p1} and R_{p2} in the parallel branch are electrically connected to one another on the substrate and comprise a shared ground connection 31-1 that is connected to a ground terminal pad 31-3 by a bond wire 31-2, which represents one part of the inductance L_{ser} . The connection on the substrate is realized here with a stripline but can also comprise a bond wire. Even though only two coupled resonators are shown here, the invention also covers filters having more than two coupled resonators.

SIXTH EMBODIMENT

{6:

[00119] The description of a sixth embodiment (**Embodiment 6**) of the present invention ~~{new follows, portions thereof being}~~ is shown in Fig. 30[-A], which uses a SAW filter of the reactance filter type having at least two parallel branches ~~{is employed}~~. In at least two of all existing parallel branches $R2$ and $R3$, the output sides (30-3 and 30-4) of the parallel resonators are ~~{already}~~ electrically connected to one another electrically on the chip. The connection 30-5 to the housing only ensues subsequently in the fabrication. The remaining parallel branches are connected to the housing independently ~~{thereof}~~. The

connection of the chip (30-1) to the housing is not implemented as described previously (as a bond connection) but is produced with a bump connection (30-5).

[00120] The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ [has] is not ~~[changed]~~ different compared to the general exemplary embodiment and ~~[can be seen]~~ shown in Fig. 13. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside. ~~[Given a structuring in]~~ For bump technology structuring, the value for the inductance L_{ser} is greatly reduced compared to an embodiment with bond wire since the bond connection itself has its nearly no inductance in contrast to a bond connection. Only the inductive part of the stripline on the chip and the housing lead-through inductance up to the external housing ground pin ~~[remaining]~~

remain.

[00121] Fundamentally, all of the exemplary embodiments ~~[shown up to now,]~~ discussed above (even though it is with more than four basic elements having at least two parallel branches at the output side already electrically connected on the chip~~[,]~~) can be realized in conjunction with the bump technology. The filter characteristics are also fundamentally comparable; however, the value that can be achieved for the serial inductance L_{ser} is lower. In order to achieve the required selections~~[,]~~ (for example, in the range of the LO suppression and/or image suppression~~[,]~~) it is thus ~~[all the more]~~ necessary to employ the inventive method for targeted variation of the stop band. The invention also offers the advantage of reducing the ~~[plurality]~~ number of necessary ground bumps and, thus, the chip area for ground terminals. ~~[As a result thereof,]~~ This results in an even further miniaturization of the overall SAW filter ~~[can be miniaturized even further]~~.

};

[00122] The above-described devices are illustrative of the principles of the present invention. Numerous modifications and adaptations will be readily apparent to those skilled in this art without departing from the spirit and scope of the present invention.

ABSTRACT

~~[SAW Filter of the Reactance Filter Type with Improved Stop Band Suppression and Method for Optimizing the Stop Band Suppression]~~

In a SAW filter of the reactance type having at least two SAW resonators ~~[(R2, R3)]~~ in two parallel branches and a SAW resonator ~~[(R1)]~~ in a serial branch, ~~[it is proposed]~~ **the invention provides** that an electrical connection fashioned on the substrate of the ground sides ~~[(12-6, 12-7)]~~ of the two SAW resonators ~~[(R2, R3)]~~ in the parallel branches ~~[be provided]~~ **is done** before the bonding ~~[(12-5)]~~ to the housing in order to achieve a shift of the pole point belonging to the parallel branch to a lower frequency.

~~[Figure 12]~~

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UNDER THE PATENT COOPERATION TREATY--CHAPTER II

SUBMISSION OF DRAWINGS


APPLICANT(S): Peter SELMEIER
ATTORNEY DOCKET NO.: P01,0534
INTERNATIONAL APPLICATION NO: PCT/DE00/02202
INTERNATIONAL FILING DATE: 06 JULY 2000
INVENTION: SAW FILTER OF THE REACTANCE FILTER TYPE WITH
IMPROVED STOP BAND SUPPRESSION AND METHOD FOR
OPTIMIZING THE STOP BAND SUPPRESSION

Assistant Commissioner for Patents,
Washington, D.C. 20231

Sir:

Enclosed are 18 sheets of drawings (Figures 1-31) for the above-
identified PCT application. Approval of the drawings is respectfully requested.

Submitted by,

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CUSTOMER NUMBER 26574

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FIG 1

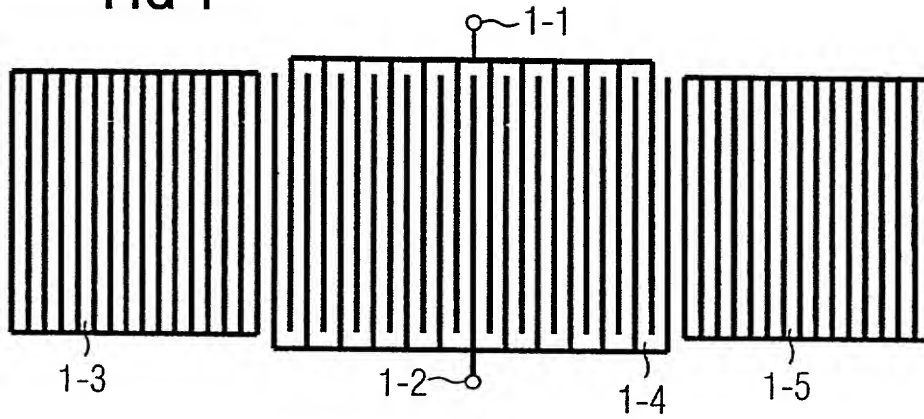


FIG 2

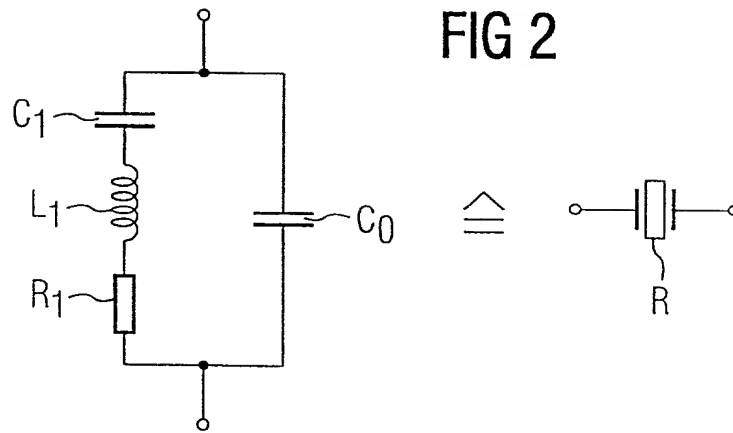
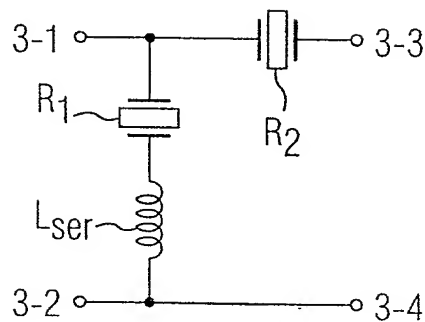


FIG 3



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FIG 4

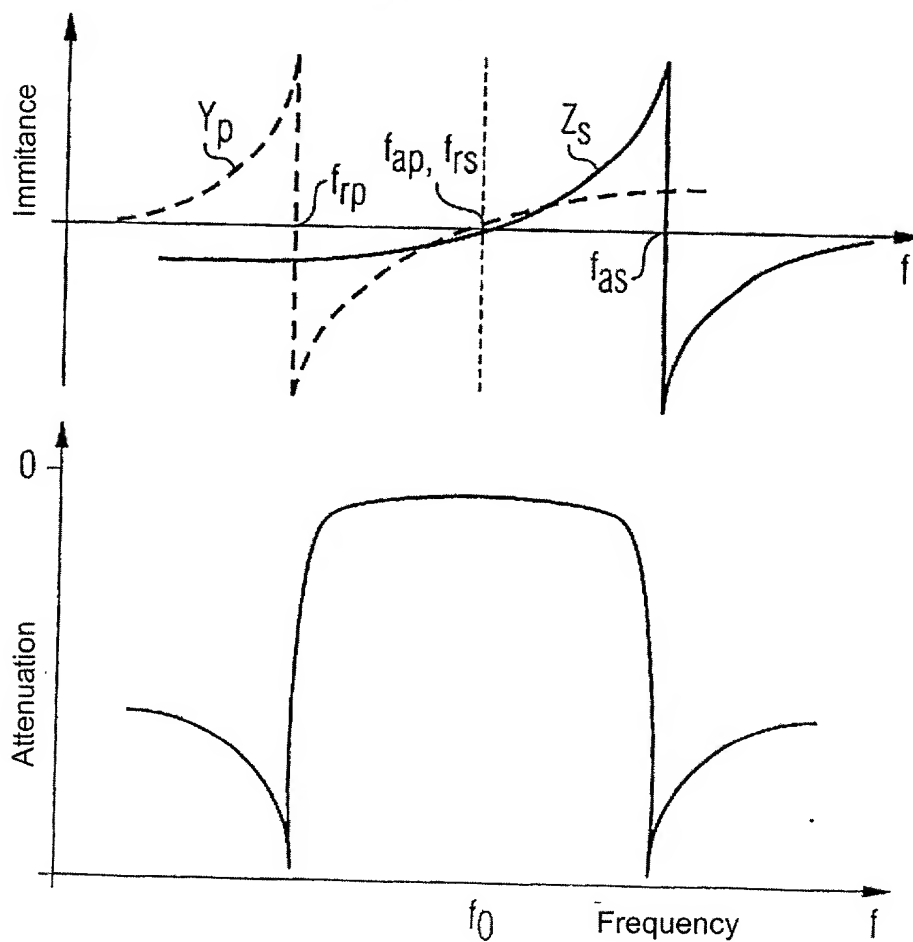
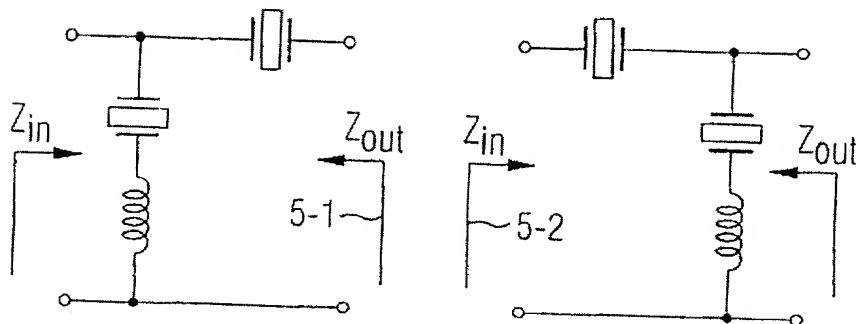


FIG 5



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FIG 6

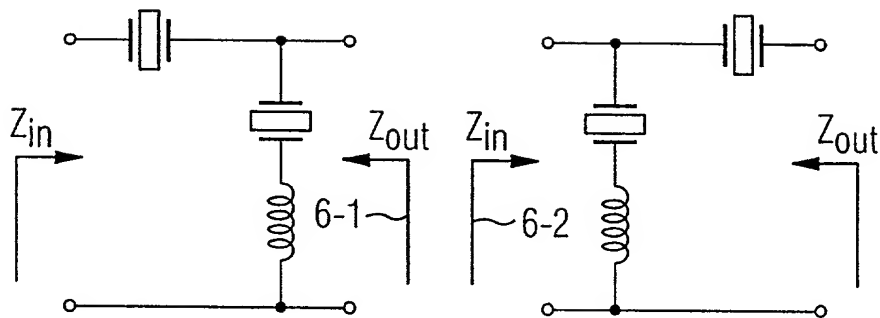


FIG 7

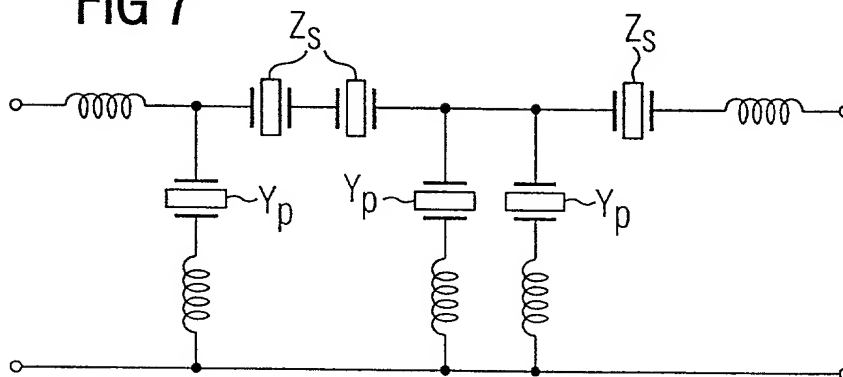
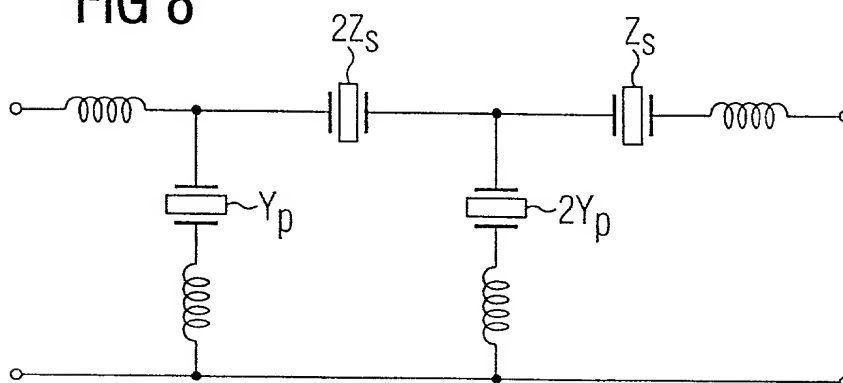


FIG 8



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FIG 9

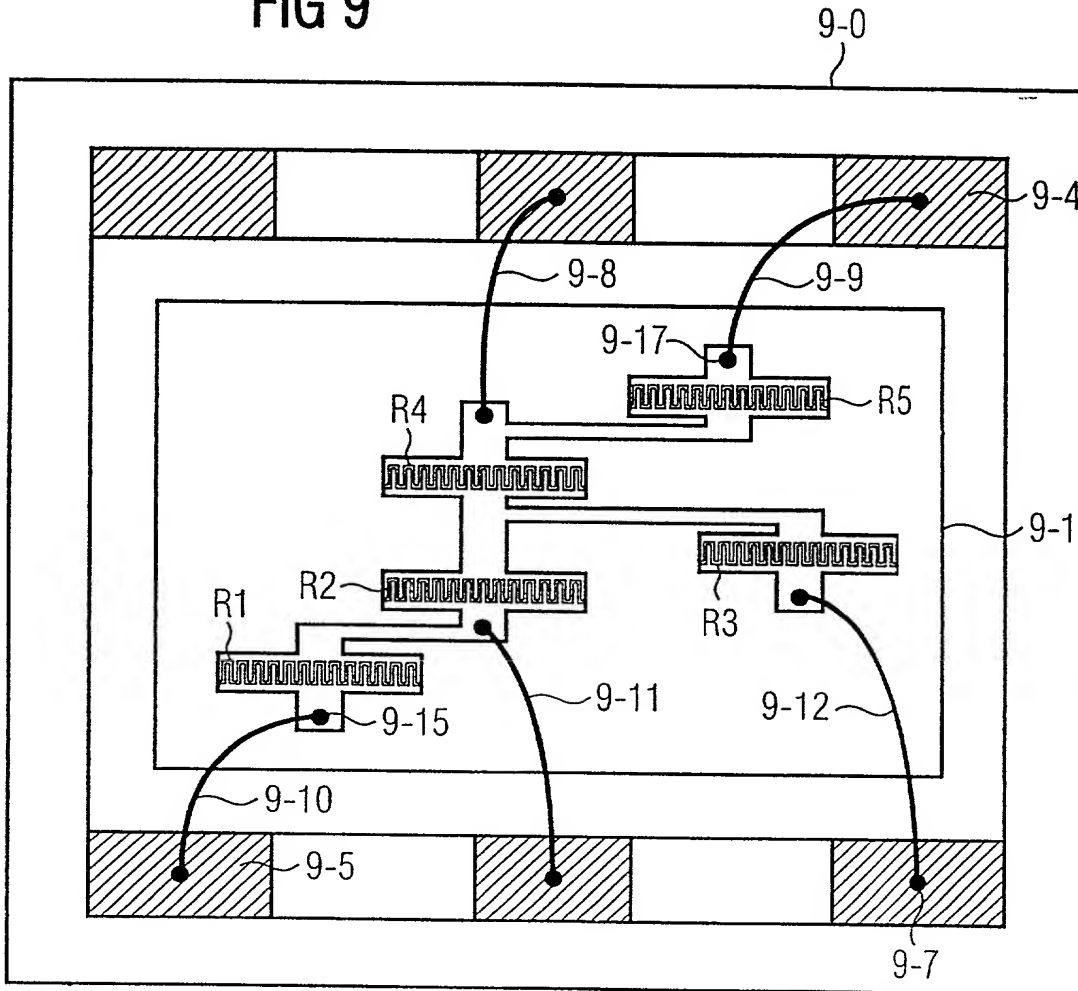
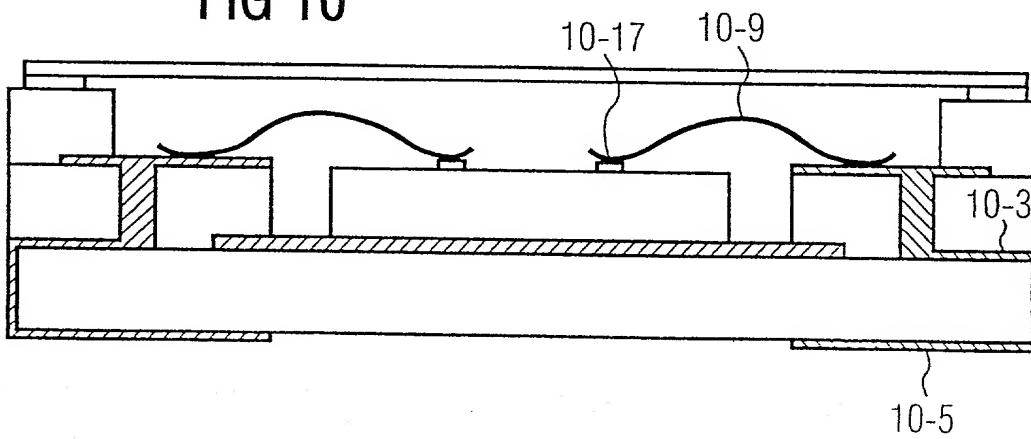


FIG 10



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FIG 11A

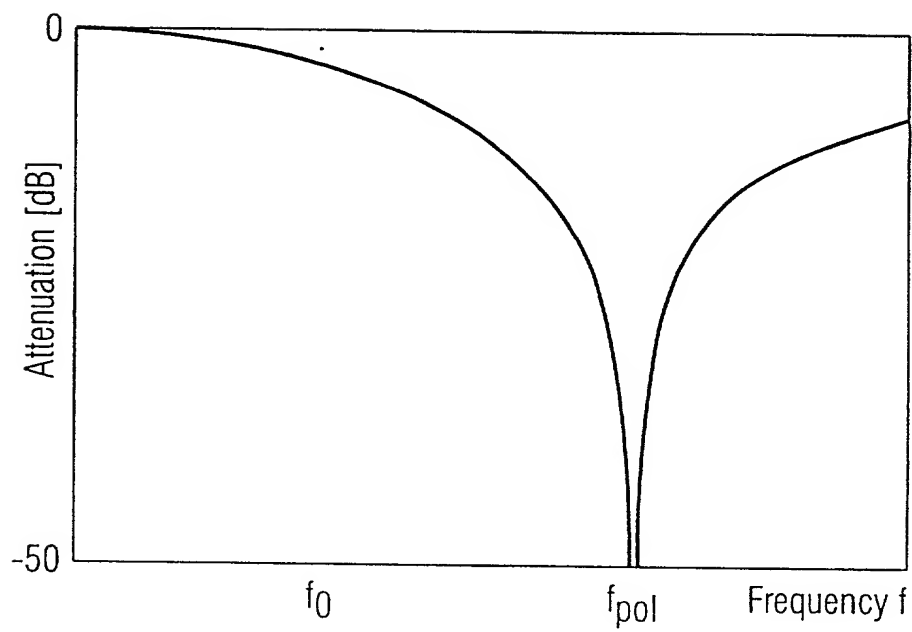
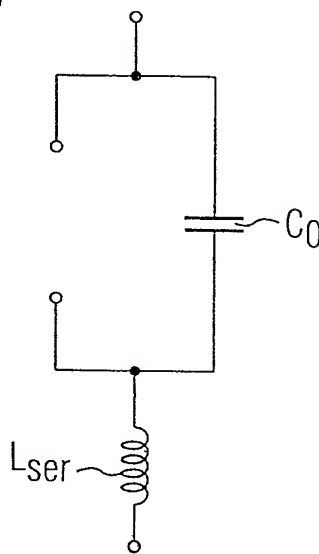


FIG 11B



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FIG 12

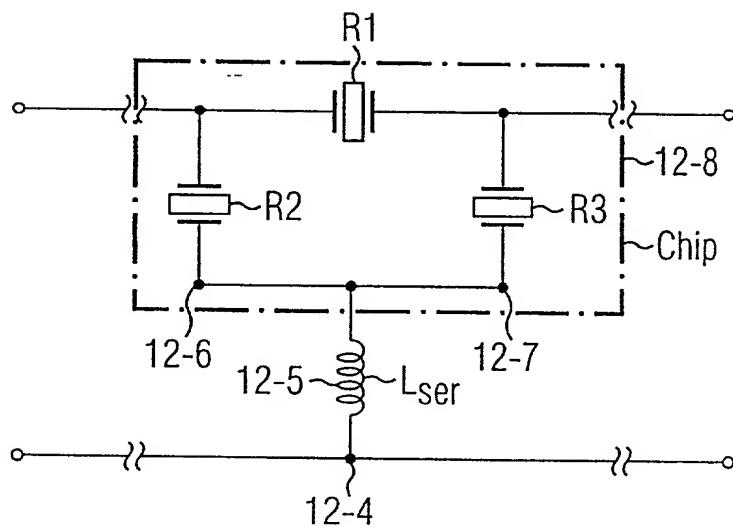
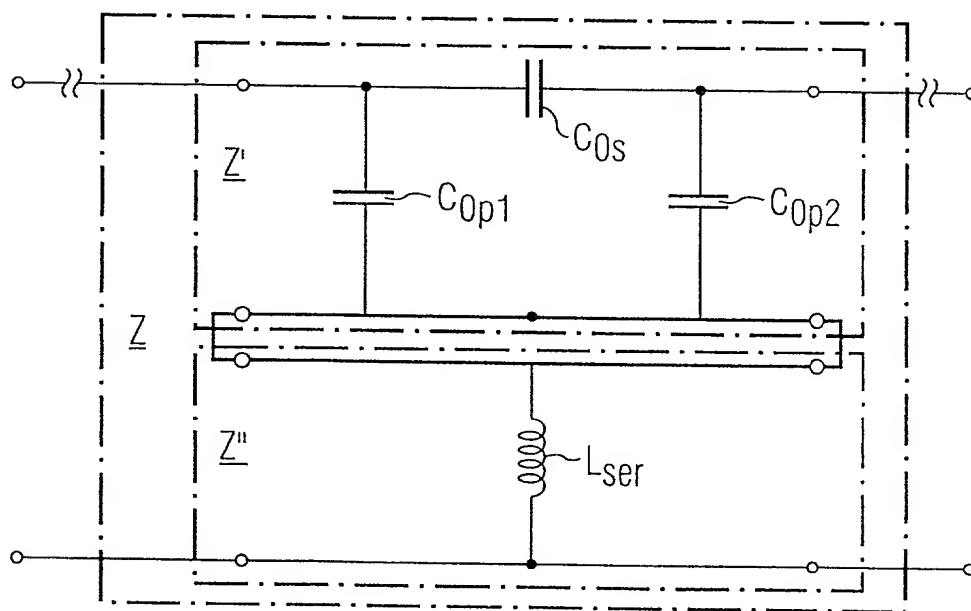


FIG 13



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FIG 14

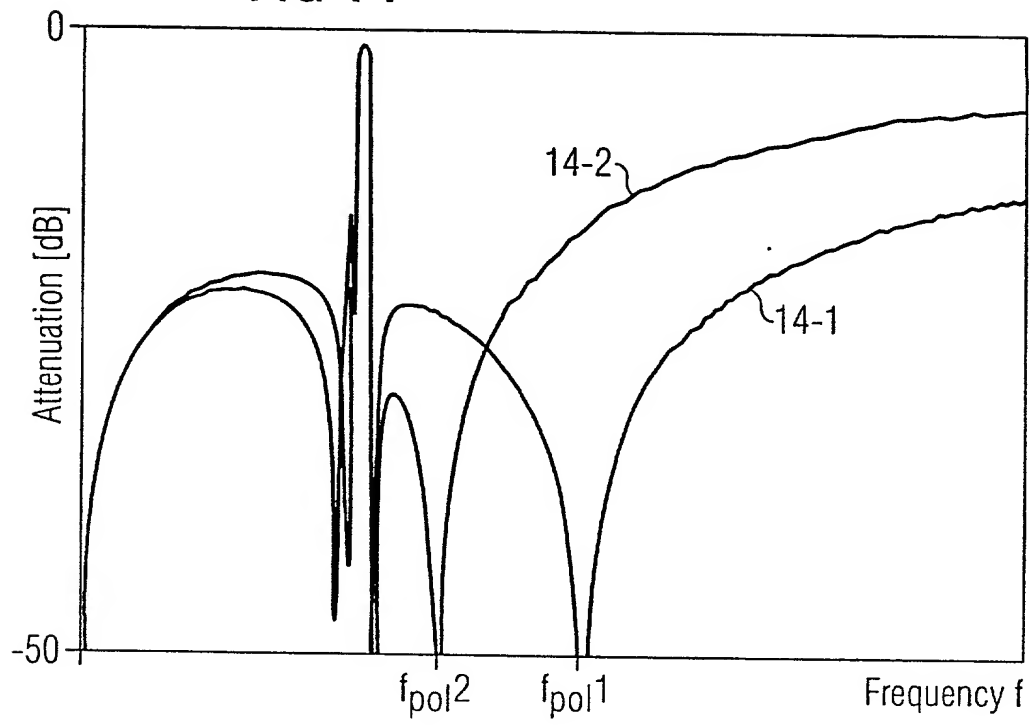
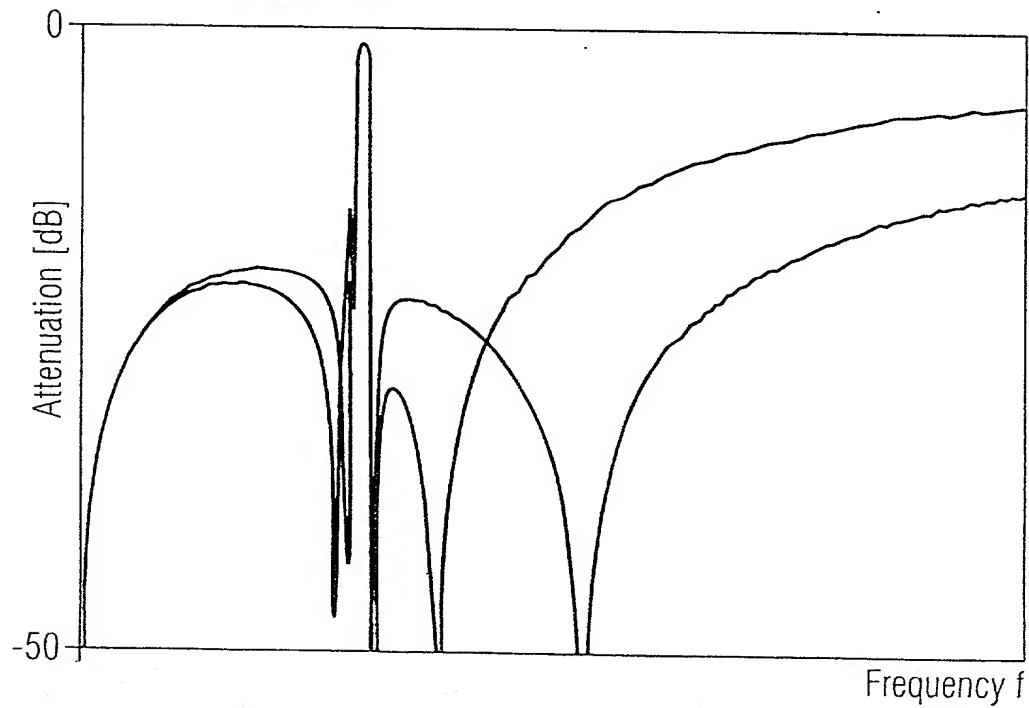


FIG 15



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FIG 16

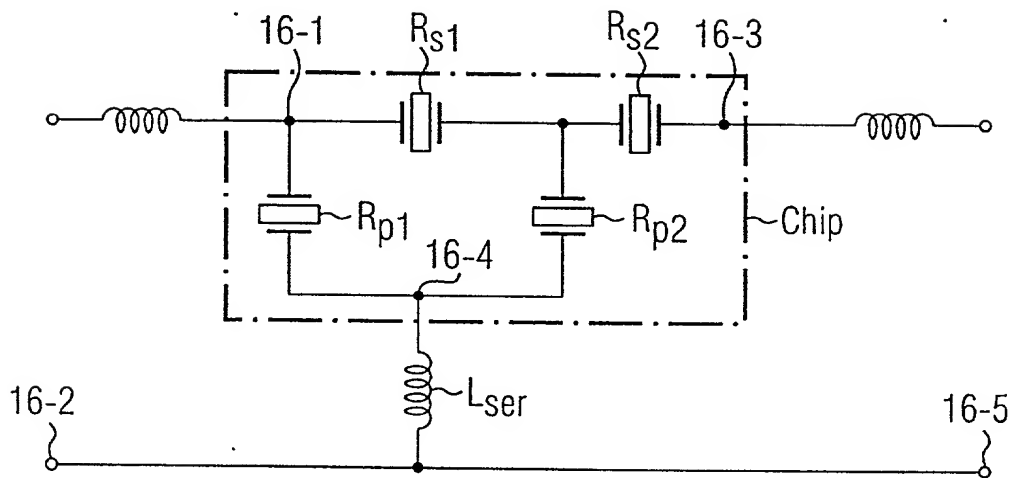
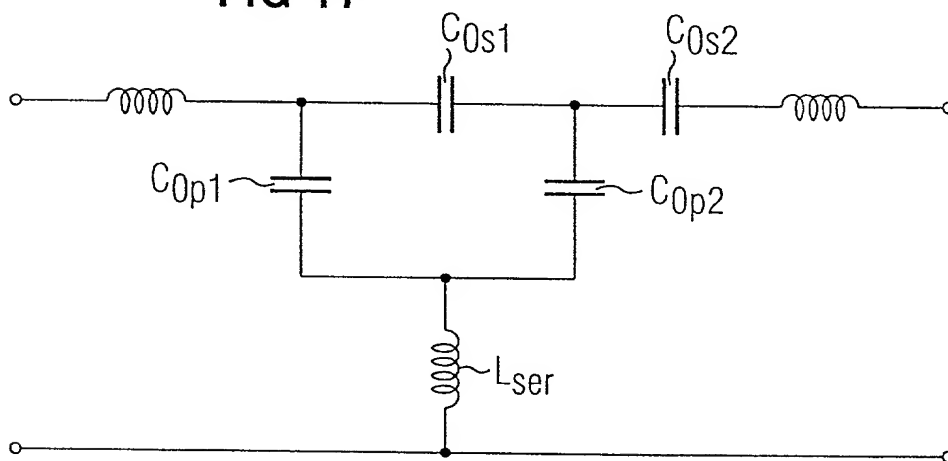
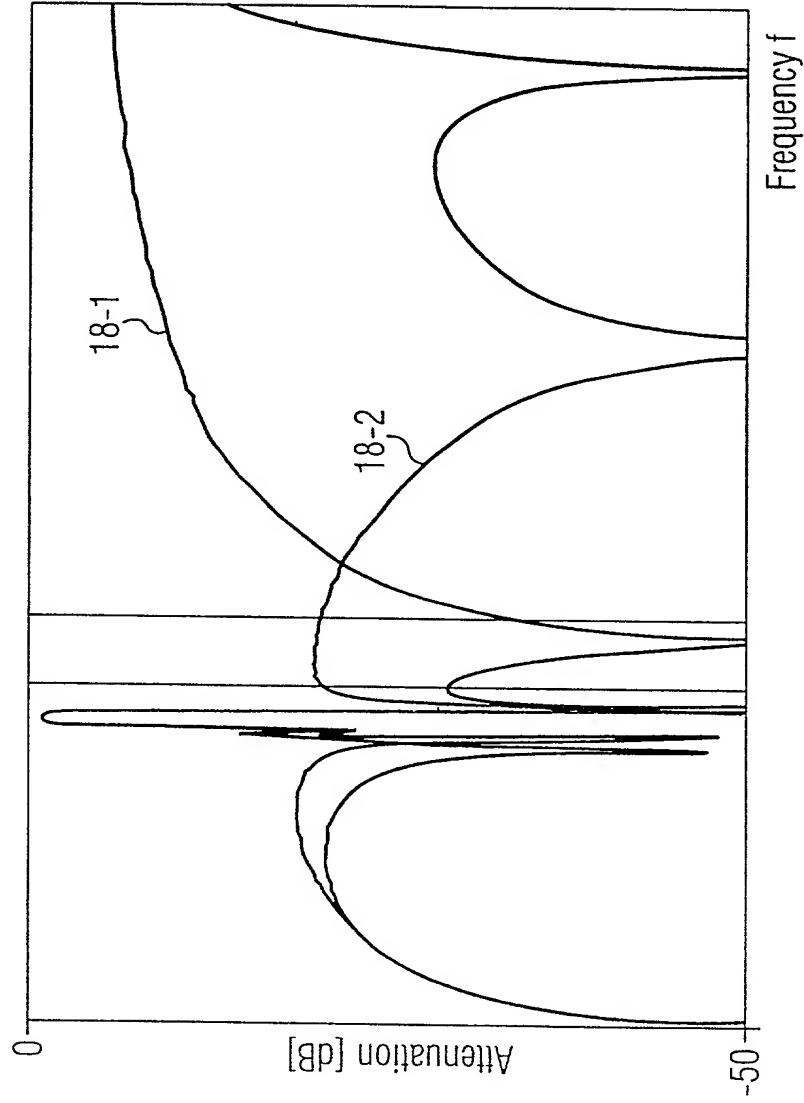


FIG 17



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FIG 18



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FIG 19

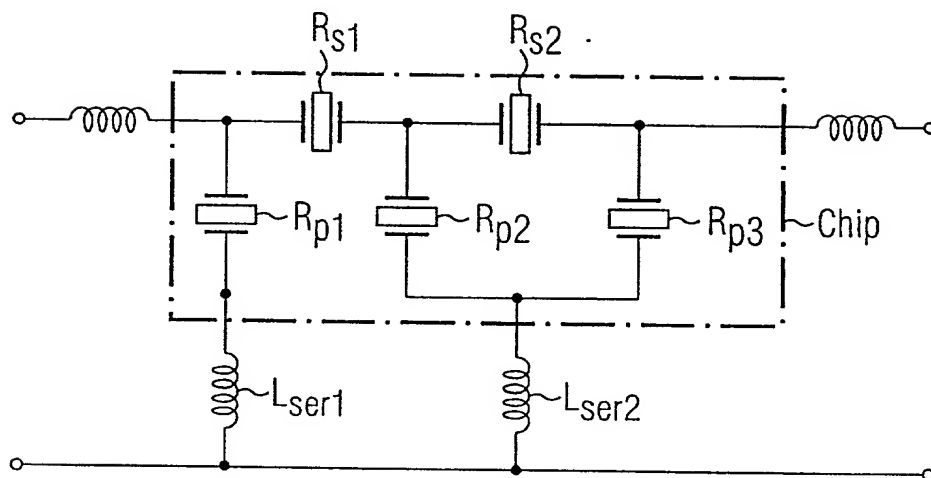
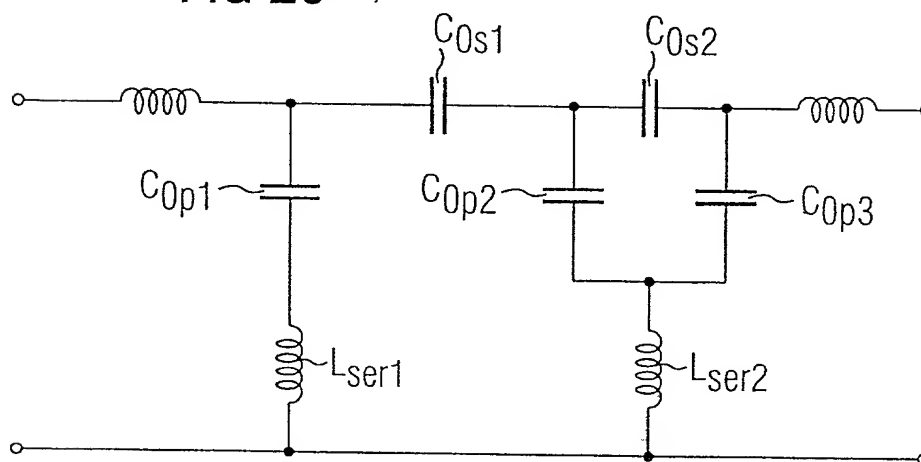
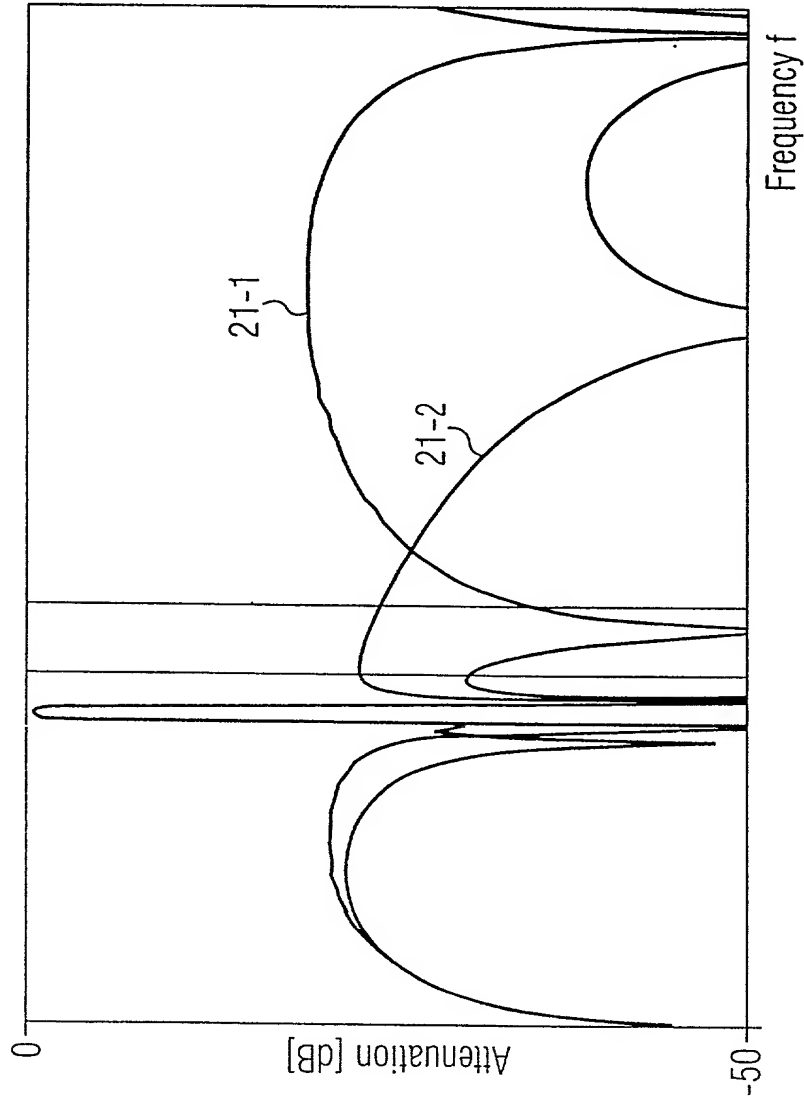


FIG 20



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FIG 21



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FIG 22

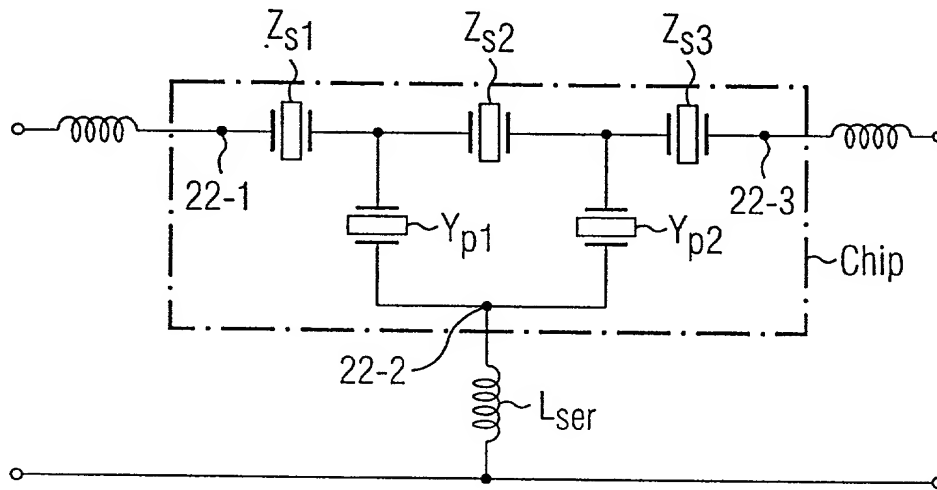
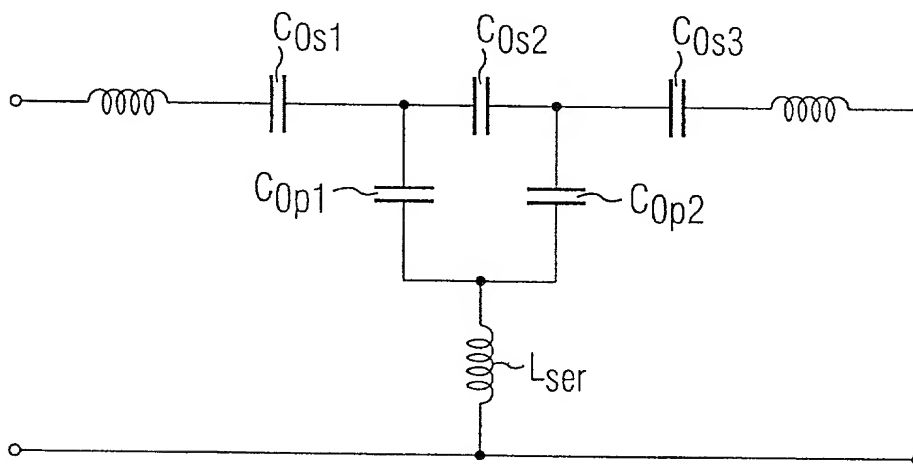
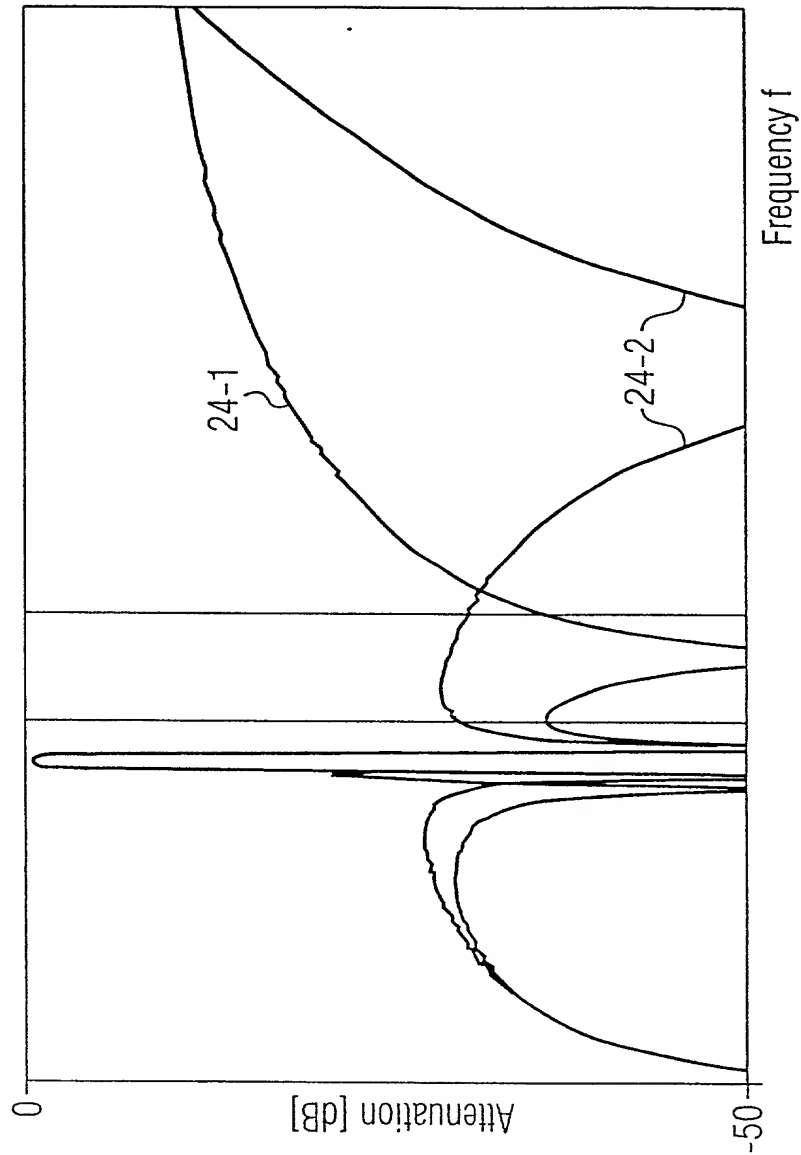


FIG 23



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FIG 24



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FIG 25

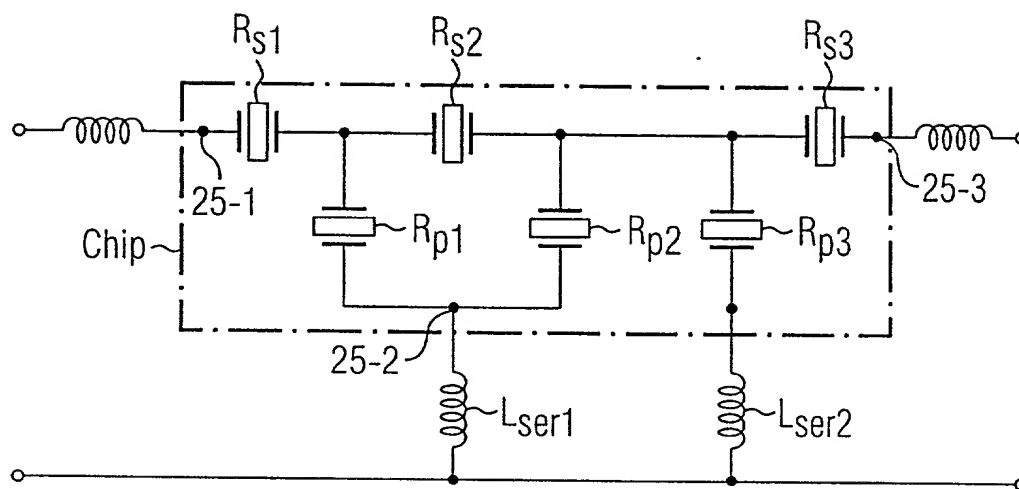
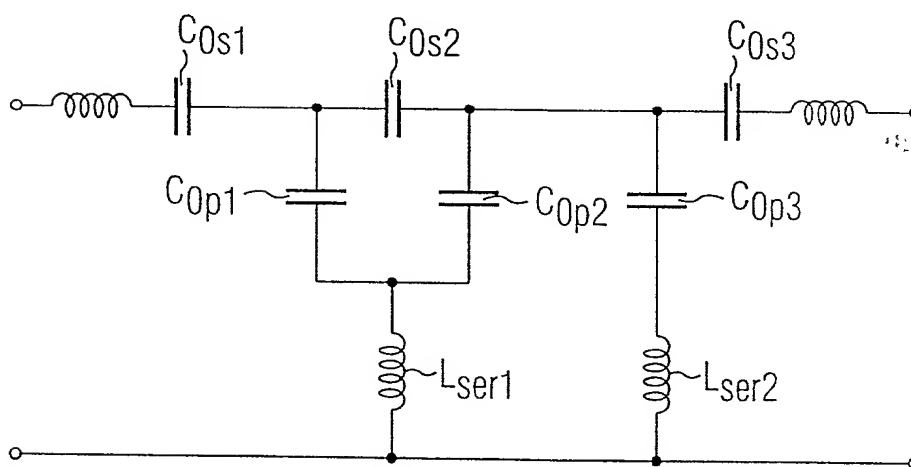
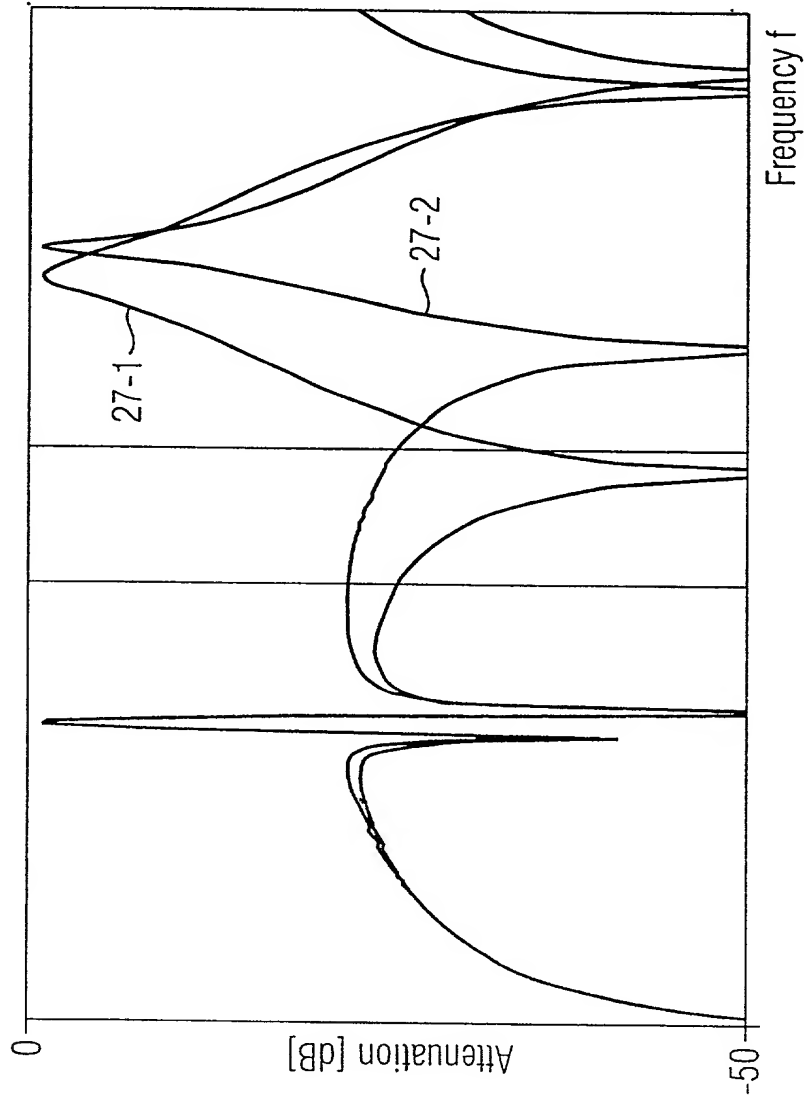


FIG 26



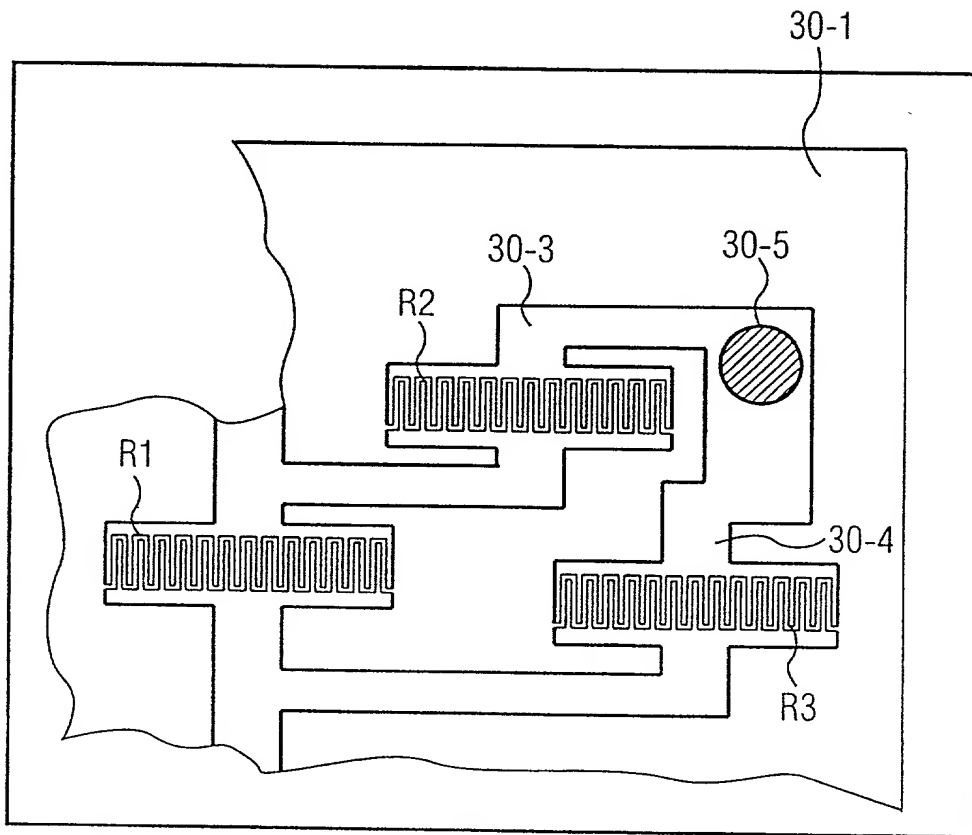
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FIG 27



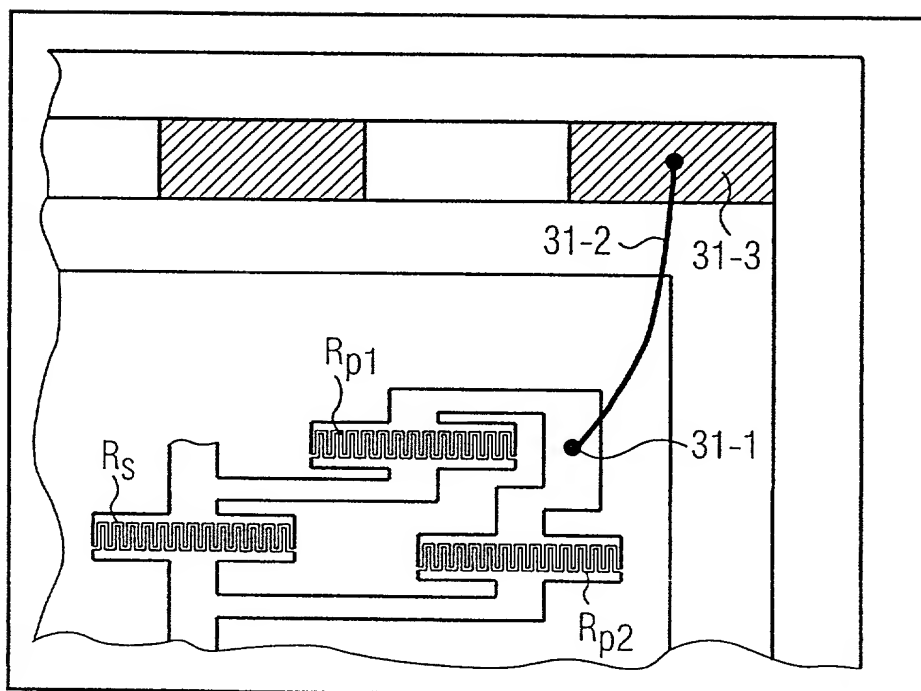
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FIG 30



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FIG 31



**SAW FILTER OF THE REACTANCE FILTER TYPE WITH IMPROVED
STOP BAND SUPPRESSION AND METHOD FOR OPTIMIZING THE STOP
BAND SUPPRESSION**

The present invention is directed to a surface-active wave filter (SAW)
5 and, specifically, to a SAW filter of the reactance filter type with improved stop band
suppression as well as to a method for the optimization of the stop band suppression.

Reactance filters are known from classical filter technology. When SAW
resonators are employed for the individual resonators instead of discrete elements
(inductances and capacitors), then this is called a SAW filter according to the
10 reactance filter type.

Given SAW filters of the reactance filter type, SAW resonators are
employed as impedance elements. Figure 1 shows the schematic structure of a known
resonator. It comprises metallic structures on the surface of a piezo-electric substrate
and has a terminal pair 1-1 and 1-2 to which an interdigital transducer 1-4 is
15 connected for the transformation of electrical energy into acoustic energy. A
reflector 1-3 and 1-5 is respectively arranged at both sides of the interdigital transducer
1-4 along the acoustic axis in order to prevent the acoustic energy from escaping.

At the left, Figure 2 shows the equivalent circuit diagram for a SAW
resonator R and shows the symbol employed for the resonator at the right. A series
20 resonant circuit composed of dynamic inductance L_1 , dynamic capacitor C_1 and
dynamic resistor R_1 (when taking losses into consideration) is located in the first
branch of the parallel circuit, and the static capacitor C_0 of the interdigital transducer
is located in the second branch. The series resonant circuit reflects the behavior of the
resonator in the resonance case, i.e. in the range of the resonant frequency f_r . The
25 static capacitor reflects the behavior in the frequency ranges $f \ll f_r$ and $f \gg f_r$. The
dynamic capacitor C_1 is proportional to the static capacitor C_0 of the interdigital
transducer:

$$C_1 \sim C_0 \quad (1.1)$$

A resonator has a resonant frequency f_r and an anti-resonant frequency f_a . The
30 following applies to the resonant frequency f_r :

$$f_r = \frac{1}{2\pi} \sqrt{L_1 * C_1} \quad (1.2)$$

The following applies for the anti-resonant frequency f_a of a resonator:

$$f_a = f_r * \sqrt{1 + \frac{C_1}{C_0}} \quad (1.3)$$

The basic unit of a SAW reactance filter is what is referred to as a basic element as shown in Figure 3. It is composed of a first resonator R_1 with resonant frequency f_{rp} and appertaining anti-resonant frequency f_{ap} in the parallel branch and of a second resonator R_2 with resonant frequency f_{rs} and appertaining anti-resonant frequency f_{as} in the serial branch. The frequency curve of the admittance Y_p of the resonator R_1 in the parallel branch and the frequency curve of the impedance Z_s of the resonator R_2 in the serial branch are shown in Figure 4. For producing a band-pass filter with the middle frequency f_0 , the resonant frequencies of the two resonators have the following relationship:

$$f_{ap} \approx f_{rs} \approx f_0 \quad (1.4)$$

Each basic element is to be fundamentally viewed as two-port with the terminals 3-1 or, respectively, 3-2 of port 1 and the terminals 3-3 or, respectively, 3-4 of port 2 (see Figure 3). At the same time, the terminals 3-1 is the input and the terminal 3-3 is the output of the series resonator. The input of the parallel resonator is connected to the terminal 3-1. The terminals 3-2 and 3-4 represent the reference ground given an asymmetrical operation. The output 3-5 of the parallel resonator that faces toward the reference ground is referred to below as output side or, respectively, ground side of the parallel resonator. The inductance L_{ser} that lies between the output side of the parallel resonator and the reference ground reflects the connection to the housing ground in the real structure.

The selection level of the SAW filter according to the reactance filter type is defined, first, by the relationship C_{0p}/C_{0s} of static capacitor C_{0p} in the parallel branch and static capacitor C_{0s} in the series branch and is defined, second by the plurality of basic elements connected following one another (cascaded).

The basic elements in the case of a cascading are usually circuited adapted, i.e. respectively mirrored. Figure 5 and Figure 6 show two examples of a reactance filter wherein respectively two basic elements are cascaded. The output impedance 5-1 (Z_{out}) or, respectively, 6-1 (Z_{in}) of the first basic element is equal to the
 5 input impedance 5-2 or, respectively, 6-2 of the second basic element, as a result whereof the losses due to mismatching are minimal. Many structures are possible or known for reactance filters with respect to the plurality and arrangement of the basic elements.

Resonators of the same type (series resonator or parallel resonator) lying
 10 immediately behind one another can also be respectively combined to form one, whereby the capacitive overall effect remains the same. The interconnection of a filter according to Figure 7 corresponds in effect to that of a filter according to Figure 8.

Figures 9 and 10 show the typical, actual structure of a SAW filter on a
 15 piezoelectric substrate 9-1 in a ceramic housing 9-0 and the typical connecting technique with bond wires 9-8 through 9-12 or, respectively, 10-9.

At the output side 9-15 through 9-17, the parallel resonators R1, R3 and R5 are connected to the housing ground pads 9-4, 9-5 and 9-7 via bond wires 9-9, 9-10 and 9-12.

As a result of the typical structuring technique (see Figure 9 and Figure
 20 10), series inductances between, for example, the output side 9-17 of the parallel resonator R5 on the substrate (chip) 9-1 and the ground 10-5 adjacent at the outer housing pin 9-4 are obtained given the connection of the parallel branches to ground. These essentially include the inductive part of the stripline on the chip, the inductance
 25 of the bond connection 9-9 and that of the housing lead-through 10-3.

These series inductances influence the behavior of the filter both in the passband as well as in the stop band. $f < f_0$ applies for the pass band. The resonant frequency and, thus, the bandwidth of a resonator can, as known, be modified by an external wiring belonging to the resonator. An inductance serially with the resonator
 30 increases the effective dynamic inductance, as a result whereof the resonant frequency f_r drops. Since the anti-resonant frequency f_a is shifted to only a very slight extent, the

bandwidth $\Delta f = f_a - f_r$ of a resonator is increased with the serial inductance. The bandwidth of the SAW filter is also increased in the case of a parallel resonator.

$f \ll f_0$ and $f \gg f_0$ applies for the stop band. Here, the equivalent circuit diagram of a resonator is reduced to its static capacitance C_0 since the series resonant circuit is extremely high-impedance beyond f_0 and corresponds to a no-load. An inductance L_{ser} serially with the resonator yields a series resonant circuit shown in Figure 11 having a resonant frequency

$$f_{pol} = 1/2\pi \sqrt{L_{ser} * C_0} \quad (1.5)$$

In the case of an inductance serially with a parallel resonator, this means that the energy of the filter can flow off directly to ground given the frequency f_{pol} ; what is referred to as a pole point thus forms in the filter curve, i.e. an increased suppression in the stop band. A plurality of pole points in the stop band corresponds to the plurality of parallel branches with series inductance. Pole points f_{pol1} and f_{pol2} that can be distinguished from one another in terms of frequency derive only given different products $\Pi_1 = L_{ser1} * C_{01}$ and $\Pi_2 = L_{ser2} * C_{02}$. When the products are identical, then the pole points lie at the same frequency; a double pole point $f_{pol} = f_{pol1} = f_{pol2}$ is obtained with a higher suppression than given a simple pole point.

Figure 11a shows the attenuation behavior of a resonator in the parallel branch to which an inductance L_{ser} is serially connected at the output side of the parallel resonator. As in Figure 11b, the series resonant circuit of the resonator whose resonant frequency $f_{rp} = f_0$ was removed in order to illustrate the pole point. What typically applies for the frequency of the pole point f_{pol} is $f_{pol} > f_0$, whereby f_0 is equal to the resonant frequency of the filter. A high attenuation is then obtained for the pole point.

SAW filters of the reactance filter type are mainly employed as RF filters in the mobile radio telephone field since they exhibit extremely low losses in the pass band. As RF filter in the mobile radio telephone field, the SAW filter of the reactance filter type must, over and above this, suppress, first, the duplex band (i.e., the reception band given a transmission filter and, conversely, the transmission band given a reception filter) and, second, must suppress the signal at the local oscillator

frequency (LO) and/or at the image frequency in order to prevent unwanted mixed products in the telephone.

The local oscillator lies above or below the middle frequencies f_0 of the filter. The distance from the middle frequency f_0 corresponds to the intermediate
 5 frequency (ZF) employed for the signal editing. The image frequency has the spacing $2 \cdot \text{ZF}$ from the middle frequency f_0 . Since momentary ZF frequencies in the range 100-400 MHz are employed, the SAW filter - dependent on the application - must comprise good attenuation properties of, typically, more than 30 dB in the range f_0 plus/minus 100-800 MHz. In the most frequent instances, the local oscillator lies
 10 above the middle frequency f_0 .

There are various possibilities for achieving an adequate attenuation in the range of the LO frequency and/or image frequency. Possibly A is comprised therein that the general selection level be made correspondingly high (the minimum attenuation below the pass band given approximately $f_0/2$ is valid as criterion for this).
 15 The great disadvantage is, however, that the losses in the pass band also increase with increasing selection level. This is unacceptable for the signal processing in the telephone in most cases. The second possibility B derives from the aforementioned fact that an inductance present given the traditional structuring technique generates a pole point serially with a parallel resonator that lies exactly at the LO or image
 20 frequency. Given the great spectrum of ZF frequencies employed, a possibility must be established in this case in order to vary the generated pole point over a range of approximately 700 MHz.

Since the static capacitance C_{op} in the parallel branch is the determining factor for the filter performance (passband, matching and selection level), it can only
 25 be varied to an extremely slight degree with given filter demands such that the position of pole points in the stop band also simultaneously changes. Likewise, the degree of freedom for the size of the inductance serially between output side of the parallel resonator and ground is limited. Due to the necessity for miniaturization as well as for cost reasons, the chips that are employed are becoming smaller and
 30 smaller, this resulting therein that the inductive part of the stripline on the chip can be varied to only a limited extent. The length and the inductance of the bond connection

correlating therewith can likewise hardly be varied any more with any housing in the course of the progressing miniaturization. Moreover, the inductance that derives from the housing lead-through is fixed for a given housing.

The possibility B is thus also not established anymore to an adequate
 5 extent for SAW filters according to the reactance filter type in housings that have been miniaturized further, namely it is no longer established to an adequate degree in order to assure the LO and/or image suppression by means of suitably placed pole points over a great frequency range from f_0 plus 100-800 MHz. Particularly given the future connection technology of "flip-chip-technique" wherein bump connections are
 10 employed instead of the bond wires, it is impossible to generate pole points at relatively low frequencies, i.e. in the range of 100 MHz above the middle frequency f_0 , since the inductances present given this structuring technique serially to the output side of a parallel resonator are too small (see Equation 1.5), and the static capacitances of the parallel branches can likewise not be selected great enough
 15 because of the required self-matching to 50Ω .

It is therefore an object of the present invention to specify a way of how a filter can be designed such that an improved stop band suppression can be obtained for specific LO frequencies and image frequencies over a possible range from 100 through 800 MHz next to the middle frequency. In particular, a way should be
 20 specified for shifting pole points of a reactance filter into a desired region close to the middle frequency f_0 without greatly influencing the remaining filter behavior.

This object is inventively achieved with a filter according to claim 1. Advantageous developments in a method for shifting pole points may be derived from further claims.

25 As a result of a connection of the ground-side output sides of the parallel branches respectively comprising a resonator on the chip, a coupling of the parallel branches is inventively produced, as a result whereof the frequency position of the appertaining pole point (also referred to as "coupled pole point" below) can be modified to a great extent. As a result thereof, it is possible to produce a SAW filter
 30 that comprises pole points at lower frequencies than could be achieved by the previous, serial interconnection of the parallel branches with existing, structure-

conditioned inductances according to Equation (1.5). It is also possible to shift one or more pole points in a given filter over a broader frequency range than was hitherto possible in a given filter. With the invention, thus, a pole point can be generated exactly at the frequency at which a high selection is required, for example at an
 5 arbitrary LO or image frequency.

Such demands for the suppression of signals at the local oscillator frequency (LO suppression) and/or at the image frequency (image suppression) can thus still be satisfied in extremely small housings having very low structure-conditioned inductances. One or more pole points can be shifted to a desired
 10 frequency given an established bond inductance, conduct inductance or housing lead-through inductance without this requiring an increase in the serial inductance. Additionally, of course, the serial inductance can also be increased.

Moreover, the plurality of ground connections that are offered can be set independently of the plurality of parallel branches employed, this leading to a lower
 15 space requirement. It is precisely in view of new connecting technologies (bump connections instead of bond connections) and new housing technologies that the embodiments according to the invention represent the sole possibility for achieving the aforementioned selection demands in miniaturized housings.

The principle for shifting the pole points according to the present
 20 invention shall be explained in greater detail below on the basis of exemplary embodiments and the appertaining figures. The following, concrete embodiments are examples of the employment in a SAW filter of the reactance filter type.

Thereby shown are:

- Fig. 1 a one-port SAW resonator;
- 25 Fig. 2 the equivalent circuit diagram and symbol for a SAW resonator;
- Fig. 3 a basic element of a SAW filter of the reactance filter type;
- Fig. 4 interaction of parallel and series resonators;
- Fig. 5 cascade of two basic elements;
- Fig. 6 cascade of two basic elements;
- 30 Fig. 7 diagram of a reactance filter;
- Fig. 8 diagram of a reactance filter with the reduced structure s-p-s-p;

- Fig. 9 plan view onto a SAW filter in the housing without cover;
- Fig. 10 cross-section through a SAW filter in the housing;
- Fig. 11a pole point;
- Fig. 11b equivalent circuit diagram for the attenuation behavior of a parallel
5 branch;
- Fig. 12 equivalent circuit diagram of a filter;
- Fig. 13 equivalent circuit diagram for the attenuation behavior of a SAW filter;
- Fig. 14 diagram that shows the relationship between ΔL_{ser} and pole point;
- Fig. 15 dependency of the frequency position of the pole point on the static
10 capacitance;
- Fig. 16 filter having three basic elements;
- Fig. 17 the equivalent circuit diagram thereof in the stop band;
- Fig. 18 the attenuation behavior thereof;
- Fig. 19 filter with four basic elements;
- 15 Fig. 20 the equivalent circuit diagram thereof in the stop band;
- Fig. 21 the attenuation behavior thereof;
- Fig. 22 filter with four basic elements;
- Fig. 23 the equivalent circuit diagram thereof in the stop band;
- Fig. 24 the attenuation behavior thereof;
- 20 Fig. 25 filter with four basic elements;
- Fig. 26 the equivalent circuit diagram thereof in the stop band;
- Fig. 27 the filter characteristic thereof;
- Fig. 28 filter with four basic elements
- Fig. 29 the equivalent circuit diagram thereof in the stop band;
- 25 Fig. 30 filter structure with bump connection;
- Fig. 31 filter structure with bond connection.

Fig. 12 shows a simple filter structure of the invention symbolically as a
equivalent circuit diagram, this being potentially part of a larger filter structure with
further basic elements. Given (at least) two of the parallel branches with the parallel
30 resonators R2 and R3, the output sides 12-6 and 12-7 are already inventively
electrically connected to one another on the chip (substrate) 12-8. Only thereafter

does a connection to the housing ground pad 12-4 comprising, for example a bond connection 12-5, ensue.

Fig. 13 shows the equivalent circuit diagram for the frequency range $f < f_0$ and $f > f_0$ wherein only the static capacitance C_0 takes effect for each resonator. The selection behavior of a SAW filter according to the reactance filter type can be largely described with this reduced equivalent circuit diagram. The inductance L_{ser} corresponds to the inductance between the connection of the parallel resonators on the chip and the housing ground pin (equals terminal for ground at the housing) outside.

A coupling of the two parallel branches already electrically connected on the chip occurs. This leads to a frequency position change of the pole points in the stop band. The frequency position of the coupled pole point can be identified on the basis of the equivalent circuit diagram from Figure 13, which shows a two port Z. The two port Z then comprises a pole point when the impedance to ground becomes zero.

$$Z_{21} = 0$$

Z_{21} is thereby a systematically referenced matrix element from the impedance matrix. For determining Z_{21} , the two port Z can be divided into a series circuit of the two-ports Z' and Z'' . The two-port Z' comprises the Π -circuit composed of the three capacitors C_{op1} , C_{op2} and C_{os} . The two-port Z'' comprises only the inductance L_{ser} . The following thus derives:

$$Z'_{21} = \frac{I}{j\omega \left(C_{op2}C_{op1} + \frac{C_{op1}C_{op2}}{C_{os}} \right)} \quad (2.1)$$

$$Z''_{21} = j\omega L_{ser} \quad (2.2)$$

Whereby j represents the imaginary number and $\omega = 2\pi f$ applies.

With

$$Z_{21} = Z'_{21} + Z''_{21} \quad (2.3)$$

it follows that

$$Z_{21} = \frac{1 - \omega^2 L_{ser} \left(C_{0p2} + C_{0p1} + \frac{C_{0p1} C_{0p2}}{C_{0s}} \right)}{j\omega \left(C_{0p2} + C_{0p1} + \frac{C_{0p1} C_{0p2}}{C_{0s}} \right)} \quad (2.4)$$

When the numerator of the expression of (2.4) becomes zero,

$$1 - \omega^2 L_{ser} \left(C_{0p2} + C_{0p1} + \frac{C_{0p1} C_{0p2}}{C_{0s}} \right) = 0 \quad (2.5)$$

Z_{21} becomes zero. The following is obtained therefrom for the frequency position of the coupled pole point:

$$f_{pol} \text{ (coupled)} = \frac{1}{2\pi \sqrt{L_{ser} \left(C_{0p2} + C_{0p1} + \frac{C_{0p1} C_{0p2}}{C_{0s}} \right)}} \quad (2.6)$$

5

It can be clearly seen compared to the pole points previously obtained without coupling of the parallel branches on the chip according to Equation (1.5).

$$f_{pol} = \frac{1}{2\pi \sqrt{L_{ser} * C_{op1}}} \quad (2.7)$$

$$f_{pol2} = \frac{1}{2\pi \sqrt{L_{ser} * C_{op2}}} \quad (2.8)$$

That the additional capacitance parts $\frac{C_{op1} C_{op2}}{C_{os}}$ and C_{op2} or, respectively,

10 C_{op1} shift the coupled pole point to a far lower frequency given the same inductance L_{ser} .

Numerical example: for a known SAW filter of the reactance filter type, the frequency f_{pol} of a pole point is calculated as:

$$f_{\text{pol } 1} = \frac{1}{2\pi} \sqrt{L_{\text{ser}} * C_{\text{op}1}} = \frac{1}{2\pi} \sqrt{1\text{nH} * 4\text{pF}} = 2.52 \text{ GHz}$$

Typical values of 1nH and 4pF were thereby assumed for the serial inductance L_{ser} and for the static capacitance C_{op} .

According to Equation 2.6 and given the same assumed values for L_{ser} and
5 C_{op} and likewise given 4pF for C_{os} ,

$$f_{\text{pol } 2} = \frac{1}{2\pi} \sqrt{1\text{nH} * (\text{rpF} + 4\text{pF} + (4\text{pF})^2 / 4\text{pF})} = 1.45 \text{ GHz}$$

derives when two parallel branches are coupled.

When a filter comprises a plurality of parallel branches, then a plurality of
parallel branches can also be connected to one another at the ground side, these also
10 continuing to be referred to as "coupled parallel branches". The plurality and
combination of the connected parallel branches plays a critical part for the frequency
position of the coupled pole points and is to be taken into consideration in the
selection of the filter structure for a desired frequency position of the pole points.

Fig. 14 indicates the dependency of the position of a coupled pole point on
15 the size of the inductance L_{ser} . The two curves 14-1 and 14-2 indicate the filter
behavior for the same filter, whereby only L_{ser} has been differently selected. A
different frequency position of the pole points derives dependent on L_{ser} , whereby the
inductance $L_{\text{ser } 1}$ belonging to $f_{\text{pol } 1}$ is smaller than $L_{\text{ser } 2}$. The shift of the pole points
toward lower frequencies is all the greater the higher the inductance L_{ser} is.

20 To a lesser extent, the frequency position of the pole point can be set by a
variation of the product of static capacitances of the coupled parallel branches

$$\Pi_p C = C_{\text{op}1} * C_{\text{op}2} \quad (2.9)$$

So that the filter behavior in the passband and the general selection level is not
modified, such a variation of the product of static capacitances in the parallel branch
25 can be implemented only upon retention of their sum:

$$\Sigma C_p = C_{\text{op}1} + C_{\text{op}2} = \text{constant} \quad (2.10)$$

The following method can be applied: the static capacitance C_{op1} of the first couple parallel resonator is increased by the same amount C_{const}

$$C_{op1}(new) = C_{op1} + C_{const} \quad (2.11)$$

by which the static capacitance C_{op2} of the second couple parallel resonator is lowered:

$$C_{op2}(new) = C_{op2} - C_{const} \quad \text{with } C_{const} < C_{op2}, \quad (2.12)$$

so that the product ΣC_p in fact changes but the sum of the static capacitances remains identical.

$$\Sigma C_p = C_{op1}(new) + C_{op2}(new) = C_{op1} + C_{op2} = \text{constant} \quad (2.13)$$

and no modifications of the passband or of the general selection level need be accepted.

When a greater frequency offset of the couple pole point is necessary, the participating static capacitances C_{op1} , C_{op2} or C_{os} can be varied. When more parallel resonators than the two parallel resonators to be coupled are present, then the sum $C_{op1} + C_{op2}$ can be raised (or lowered), and the static capacitance of a non-coupled parallel resonator can be lowered (or raised) for balancing such that the total sum of all static capacitances remains the same in the parallel branches. The general selection level is retained as a result thereof.

Fig. 15 shows how, given a constant inductance L_{ser} , the frequency of the couple pole point is increased as a result of a reduction of the sum of the static capacitances $C_{op1} + C_{op2}$ of the coupled parallel branches, being increased by the factor 1.2. For balancing, the static capacitance of a further parallel branch was correspondingly increased.

Another possibility for shifting the couple pole point is comprised in intentionally splitting a parallel resonator P into two individual resonators P' and P'' parallel to one another, whereby the sum of the capacitances of the split, individual resonators is equal to the original capacitances C_{op} :

$$C_{op} = C'_{op} + C''_{op}$$

When one of these parallel resonators P' is coupled with a further parallel resonator but not with the parallel resonator P'', then the frequency position of the

coupled pole point can be set on the base is of the division ratio $\frac{C'_{\theta p}}{C''_{\theta p}}$ of the static

capacitance of the split parallel resonators P' and P'', since $C'_{\theta p}$ influences the frequency position of the coupled pole point.

A single series resonator or a plurality of series resonators can be arranged
 5 between coupled parallel branches. Since the size of the static capacitance C_{0s} that lies between the coupled parallel resonators influences the frequency position of the coupled pole point according to Equation 2.6, the frequency position of the coupled pole point can likewise be shifted with the following method.

When further series resonators S_n in addition to the series resonator or
 10 resonators S lying between the coupled parallel branches are present, then the static capacitance C_{0s} thereof can be raised (or lowered) and, for balancing, the static capacitance of the series resonators S_n that do not lie between the coupled parallel resonators can be lowered (or raised) such that the total sum of all static capacitances in the series branches remains the same. As a result thereof, the general selection
 15 level is retained and the frequency position of the coupled pole point is modified.

As already explained, the range for the variation of the static capacitances C_p in the parallel branch and of the serial inductances L_{ser} (between the connection of the parallel branch on the chip and the outside terminal at the housing) is limited. The same is therefore also true for the frequency range in which the pole points can be
 20 displaced. In contrast to the measures known from the prior art, however, the range of variation achieved according to the invention enables the manufacture of SAW filters - even given extremely miniaturized housings - with a LO suppression and image suppression that is required for the employment as RF filter in the mobile radio telephone field.

25 Concrete embodiments of inventive filters are now recited below.

Embodiment 1 (also see Fig. 16 through Fig. 18):

A structure having three basic elements is employed. A first basic element is connected such to the input port 16-1 that both the parallel branch as well as the series branch comprise a connection to the input port. The second basic element is connected according to the matching demand $Z_{out} = Z_{in}$. The third basic element follows in the same way. Differing from the case at the input port, only one series branch is thus directly connected to the output port. A sequence $p-s - s-p - p-s$ for the resonators derives from the input to the output, whereby p stands for parallel resonator and s stands for series resonator. Fundamentally, input port and output port can be interchanged without modifying the filter properties, whereby the sequence $s-p-p-s-s-$
 10 p derives.

As known, identical resonators can also be combined upon retention of their capacitive effect. The following structures with minimum number of resonators thus derive:

$p-s-p-s$ or, respectively, $s-p-s-p$
 15 however, mixed forms having partial combination of the resonators area also possible:
 $p-s-p-p-s$ or, respectively, $s-p-p-s-p$
 $p-s-s-p-s$ or, respectively, $s-p-s-s-p$

For the sake of simplicity, the embodiments below are only explained on the basis of minimum of resonators and without additional indication of the interchangeability of input port and output port and are shown this way in the Figures. Nonetheless, the invention also comprises modifications according to the example that has just been explained above.

Fig. 16 symbolically shows the structure of embodiment 1. The two parallel branches are already electrically connected to one another on the chip and a connection to the housing only ensues subsequently. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Fig. 17. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside.

The filter has a filter characteristic as identified by curve 18-1 in Fig. 18.
 30 The comparison to filter curve 18-2 (corresponding to the filter shown in Fig. 8) wherein the parallel branches on the chip are not connected to one another, clearly

shows how the frequency position of the pole points in the stop band with a typical inductance $L_{ser} = 1.0 \text{ nH}$ is shifted by the connection of the parallel branches on the chip. The selection is increased by more than 10 dB in the frequency range between the vertical lines (typical frequency range for LO suppression and image suppression given low intermediate frequency).

Embodiment 2 (also see Fig. 19 - Fig. 21):

Fig. 19 symbolically shows the structure of a second inventive embodiment wherein a structure having four basic elements is employed. A first basic element is connected such to the input port 19-1 that both the parallel branch as well as the series branch comprise a connection to the input port. The second basic element is connected according to the matching requirement $Z_{out} = Z_{in}$. Basic element 3 and 4 follow in the same way. Just as at the input port, both a parallel branch as well as a series branch are thus directly connected to the output port 19-3. A sequence for the resonators from the input to the output derives as follows:

$$p-s-p-s-p$$

whereby p stands for parallel resonator and s stands for series resonator. Resonators of the same type are already combined.

Two of the three parallel branches are already electrically connected to one another on the chip and a connection to the housing only ensues subsequently via the inductance L_{ser2} . The remaining parallel branch is connected to the housing independently thereof via the inductance L_{ser1} . The equivalent circuit diagram for the selection behavior in the range $f < f_0$ and $f > f_0$ is shown in Fig. 20. The inductance L_{ser2} corresponds to an inductance between the connection 19-4 of the parallel resonators on the chip (shown with the broken line in the Fig.) and the housing ground pin outside.

In Fig. 21, the curve 21-1 shows the filter characteristic of the filter from Fig. 19. The comparison with the filter curve 21-2 wherein the parallel branches are not connected on the chip clearly shows how the frequency position of the pole points in the stop band given a typical inductance $L_{ser2} = 1.0 \text{ nH}$ is shifted toward lower frequencies due to the connection of two of the three parallel branches on the chip

here. The selection is increased by approximately 10 dB in the frequency range between the vertical lines (typical frequency range for LO suppression and image suppression at low intermediate frequency).

Embodiment 3 (also see Fig. 22 - Fig. 24):

5 Fig. 22 symbolically shows the structure of the inventive embodiment 3. A structure having three basic elements is employed. A first basic element is connected such to the input port 22-1 that only the series branch comprises a connection to the input port. The second basic element is connected according to the matching requirement $Z_{out} = Z_{in}$. Basic element 3 and 4 follow in the same way. Just
10 as at the input port, only one series branch is thus directly connected to the output port 22-3. A sequence for the resonators from the input to the output derives as follows:

$$s-p-s-p-s$$

whereby p stands for parallel resonator s stands for series resonator. Resonators of the same type are already combined. The two parallel branches are already electrically
15 connected to one another on the chip and a connection to the housing only ensues subsequently. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Fig. 23. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside. The filter from 22 has a filter characteristic as identified by curve 24-1 in
20 Fig. 24. The comparison to the filter curve 24-2, whereby the parallel branches are not connected on the chip, it clearly shows how the frequency position of the pole points in the stop band given a typical inductance $L_{ser} = 1.0$ nH is shifted due to the connection of the two parallel branches on the chip. The selection is increased by more than 8 dB in the frequency range between the vertical lines (typical frequency
25 range for LO suppression and image suppression at high intermediate frequency).

Embodiment 4 (also see Fig. 25 - Fig. 27):

Fig. 25 symbolically shows the structure of the inventive embodiment 4. A structure and four basic elements is employed. A first basic element is connected such to the input port 25-1 that only the series branch having the resonator R_{S1}

comprises a connection to the input port. The second basic element is connected mirrored because of the matching demand $Z_{out} = Z_{in}$. Basic element 3 and 4 follow in the same way. Just as at the input port, only one series branch is thus directly connected to the output port 25-3. A sequence for the resonators from input to output derives as follows:

s-p-s-p-s

Resonators of the same type are already combined; in contrast to the embodiment 3, however, one parallel branch has been intentionally divided again. The division ensues such that each parallel resonator R_{p2} , R_{p3} forms its own two-port with its own electrical inputs and outputs. The combined parallel branch having the resonator R_{p1} together with one of the non-combined, two parallel branches (R_{p2}) are already electrically connected to one another on the chip at .25-2, and a connection to the housing only ensues subsequently via L_{ser1} . The remaining parallel branch (R_{p3}) is connected to the housing independently thereof. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Figure 26. The inductance L_{ser1} corresponds to an inductance between the connection of the parallel resonators R_{p1} and R_{p2} on the chip and the housing ground pin outside; the inductance L_{ser2} corresponds to an inductance between the parallel resonator R_{p3} on the chip and the housing ground pin outside.

The filter from Fig. 25 has a filter characteristic that is characterized by curve 27-1 in Fig. 27. The comparison to the filter curve 27-2, wherein the output sides of the parallel branches are not connected on the chip, clearly shows how the frequency position of the pole points in the stop band given a typical inductance $L_{ser1} = 1.0$ nH is shifted due to the connection of two of the three parallel branches on the chip. The selection is increased generally by more than 5 dB in the frequency range between the vertical lines (typical frequency range for LO suppression and image suppression given high intermediate frequency). The selection gain is far more than 10 dB when either a high LO suppression or image suppression is demanded.

Embodiment 5 (also see Fig. 28-Fig. 30):

Fig. 28 symbolically shows the structure of the inventive embodiment 5. A structure having four basic elements is employed. A first basic element is connected such to the input port 28-1 that only the series branch comprises a connection to the input port. The second basic element is connected according to the matching demand $Z_{out} = Z_{in}$. Basic element 3 and 4 following in the same way. Just as at the input port, only one series branch is thus directly connected to the output port 28-3. A sequence for the resonators from input to output derives as follows:

s-p-s-p-p-s

Resonators of the same type are already combined similar to embodiment 4; however, one parallel branch is intentionally divided again. The division, however, does not ensue into two parallel resonators that are independent of one another but in the form of a three-port. The input 4 both parallel resonators is composed of a shared terminal strip 28-4 at which the interdigital fingers to be excited lie. The terminal strip of the output is divided into two bus bars 28-5 and 28-6, whereby each bus bar corresponds to the output of one of the two parallel resonators.

The parallel branch with the resonator R_{p1} together with one of the non-combined parallel resonators R_{p2} are already electrically connected to one another on the chip at the ground output 28-2. A connection to the housing only ensues subsequently. The remaining parallel branch with the parallel resonator R_{p3} is connected to the housing independently thereof. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Fig. 29. It is basically comparable to the equivalent circuit diagram in Fig. 26. The inductance L_{ser1} corresponds to an inductance between the connection of the parallel resonators R_{p1} and R_{p2} on the chip and the housing ground pin outside; the inductance L_{ser2} corresponds to a further inductance between the non-coupled resonator R_{p3} and the housing ground pin outside.

The filter from Fig. 28 has a filter characteristic that does not differ from the filter from Fig. 26 and is therefore also characterized by curve 27-1 in Fig. 27. In contrast to the embodiment 4, a different form of the division of a parallel resonator is shown here, this differing essentially in the layout but not in the effect on the selection behavior.

Fig. 31 shows portions of an inventive filter structure as a schematic plan view onto a substrate. The resonators R are shown as interdigital transducers. The two coupled resonators R_{p1} and R_{p2} in the parallel branch are electrically connected to one another on the substrate and comprise a shared ground connection 31-1 that is

5 connected to a ground terminal pad 31-3 by a bond wire 31-2, which represents one part of the inductance L_{ser} . The connection on the substrate is realized here with a stripline but can also comprise a bond wire. Even though only two coupled resonators are shown here, the invention also covers filters having more than two coupled resonators.

Embodiment 6:

The description of a sixth embodiment of the present invention now follows, portions thereof being shown in Fig. 30. A SAW filter of the reactance filter type having at least two parallel branches is employed. In at least two of all existing parallel branches R2 and R3, the output sides (30-3 and 30-4) of the parallel resonators are already electrically connected to one another electrically on the chip. The connection 30-5 to the housing only ensues subsequently. The remaining parallel branches are connected to the housing independently thereof. The connection of the chip (30-1) to the housing is not implemented as previously as a bond connection but is produced with a bump connection (30-5).

The equivalent circuit diagram for the selection behavior in the range $f < f_0$ and $f > f_0$ has not changed compared to the general exemplary embodiment and can be seen in Fig. 13. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside. Given a structuring in bump technology, the value for the inductance L_{ser} is greatly reduced compared to an embodiment with bond wire since the bond connection itself has its nearly no inductance in contrast to a bond connection. Only the inductive part of the stripline on the chip and the housing lead-through inductance up to the external housing ground pin remaining.

Fundamentally, all of the exemplary embodiments shown up to now, even though it is with more than four basic elements having at least two parallel branches at the output side already electrically connected on the chip, can be realized in conjunction with the bump technology. The filter characteristics are also fundamentally comparable; however, the value that can be achieved for the serial inductance L_{ser} is lower. In order to achieve the required selections, for example in the range of the LO suppression and/or image suppression, it is thus all the more necessary to employ the inventive method for targeted variation of the stop band. The invention also offers the advantage of reducing the plurality of necessary ground bumps and, thus, the chip area for ground terminals. As a result thereof, the overall SAW filter can be miniaturized even further.

Patent Claims

1. Method for shifting a pole point in an SAW filter

5 comprising at least one basic element (R1, R2) fashioned on a piezoelectric substrate (12-8), said basic element comprising a first SAW resonator (R2) in a parallel branch and a SAW resonator (R1) in a serial branch,

comprising at least a further SAW parallel resonator (R3) in a further parallel branch,

10 whereby the ground sides (12-6, 12-7) of the first SAW resonator (R1) and of the further SAW parallel resonator (R3) in the further parallel branch are electrically connected on the substrate and thereby coupled, whereby the coupling is arranged between the substrate and the bonding (12-5) to the housing,

15 characterized in that

the static capacitance C_{0p} of at least one of the coupled parallel resonators is raised or lowered and, for compensation, the static capacitance of one or more non-coupled parallel resonators is lowered or raised such that the overall sum ΣC_{0p} of the static capacitances of all parallel resonators remains identical.

20 2. Method according claim 1, whereby the static capacitance C_{0s} of at least ones series resonator between two resonators in the parallel branch connected at the ground side is raised or lowered compared to a starting value and, for compensation, the static capacitance of one or more series resonator not lying in the serial branch between the coupled parallel resonators is lowered or raised such that the overall sum
25 ΣC_{0s} of the static capacitances of all series resonators remains identical.

3. Method according to one of the claims 1 or 2, whereby a parallel resonator is divided into parallel resonators P' and P'' , whereby one of the parallel resonators P' and P'' is coupled to a further parallel resonator, and

whereby the static capacitance C_{op} of one of the two coupled parallel resonators is varied by means of the division ratio of the static capacitances of the divided parallel resonators P' and P'' and, thus, the frequency position of the coupled pole point is set.

4. Method according to one of the preceding claims, whereby the product ΠC_{op} of the static capacitances C_{op1} and C_{op2} of the parallel resonators electrically connected at the output side is varied in that the static capacitance C_{op1} of the first parallel resonator is raised by the same amount C_{const} by which the static capacitance C_{op2} of the second parallel resonator is lowered, so that the sum of the static capacitances remains identical.

5. Method according to one of the preceding claims, whereby the link to the housing is undertaken with a bond connection.

6. Method according to one of the claims 1 through 4, whereby the link to the housing is undertaken with a bump connection.

7. Method according to one of the preceding claims, whereby the coupling of the two parallel resonators is undertaken with a bond connection.

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FIG 1

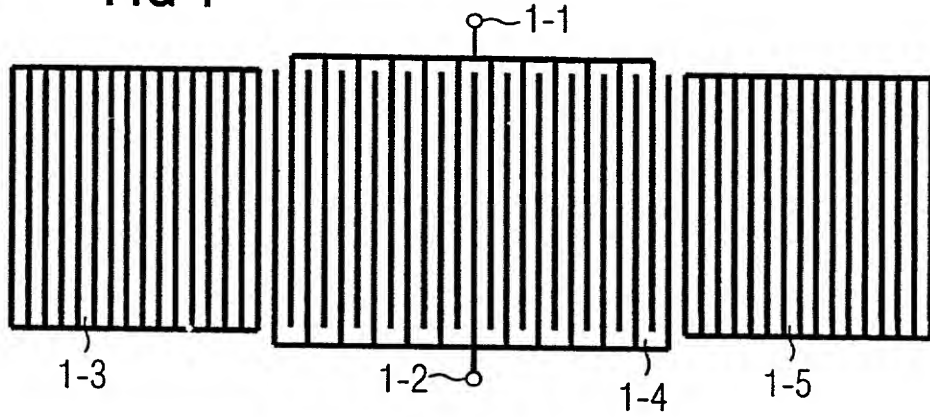


FIG 2

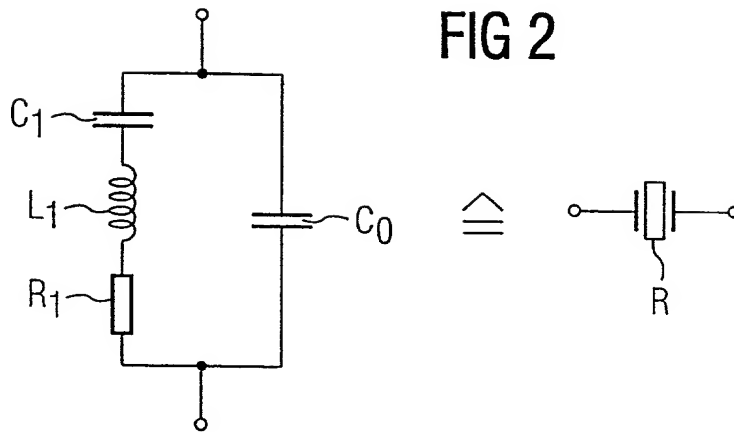
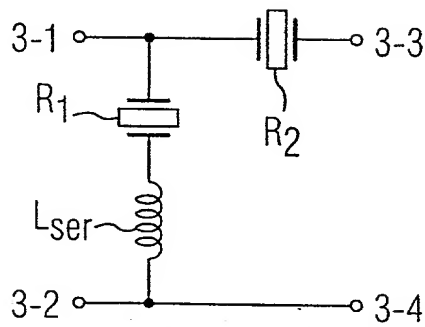


FIG 3



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FIG 4

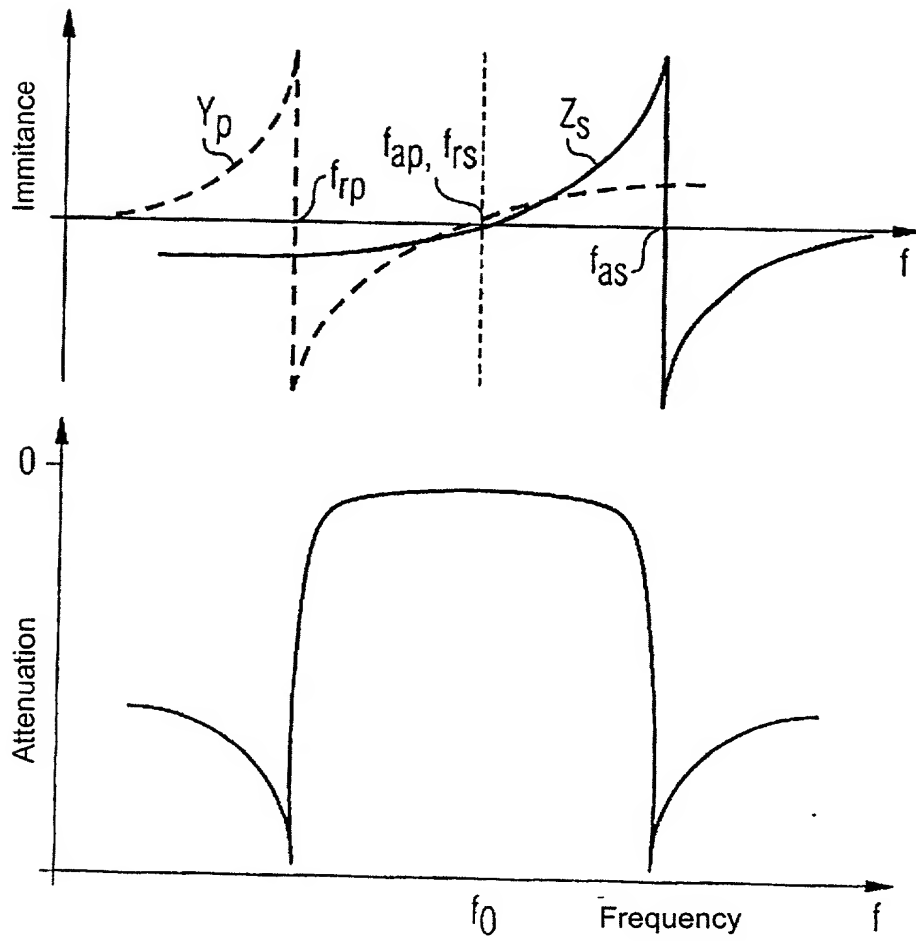
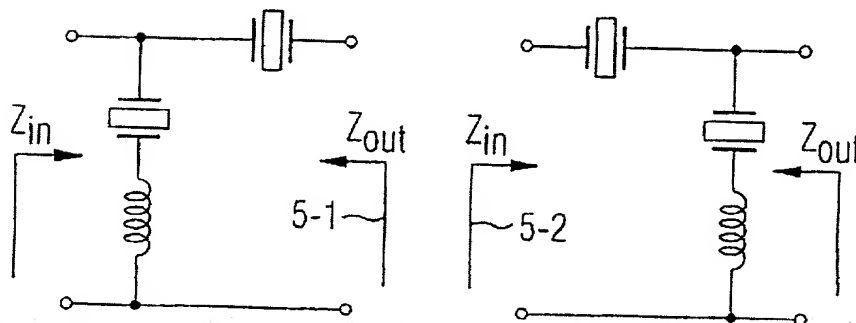


FIG 5



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FIG 6

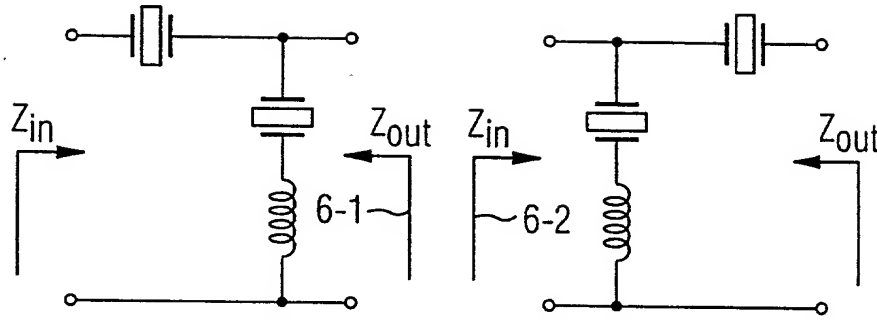


FIG 7

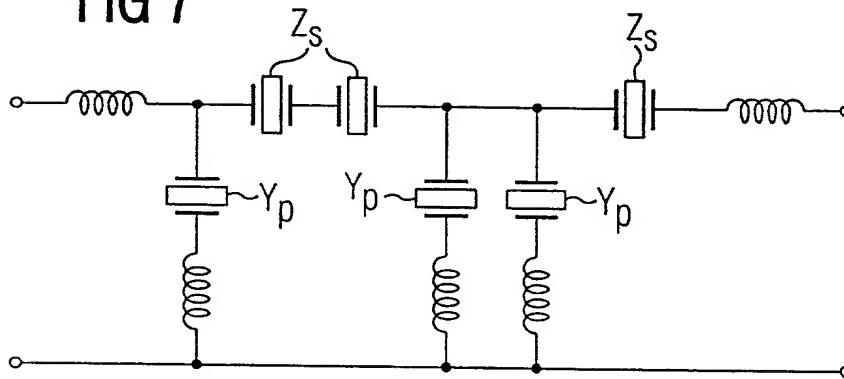
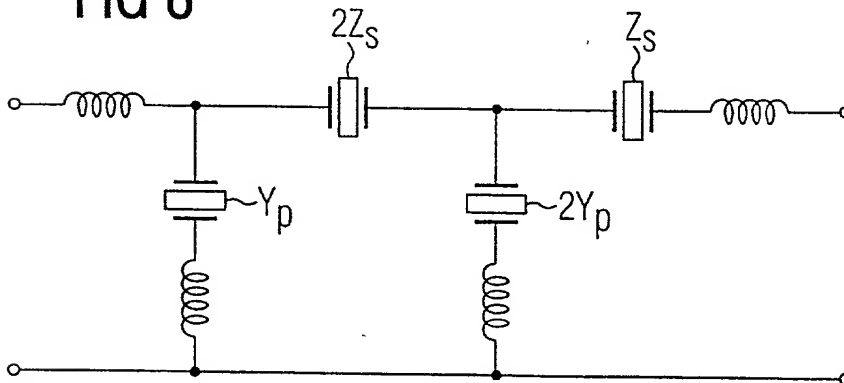


FIG 8



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FIG 9

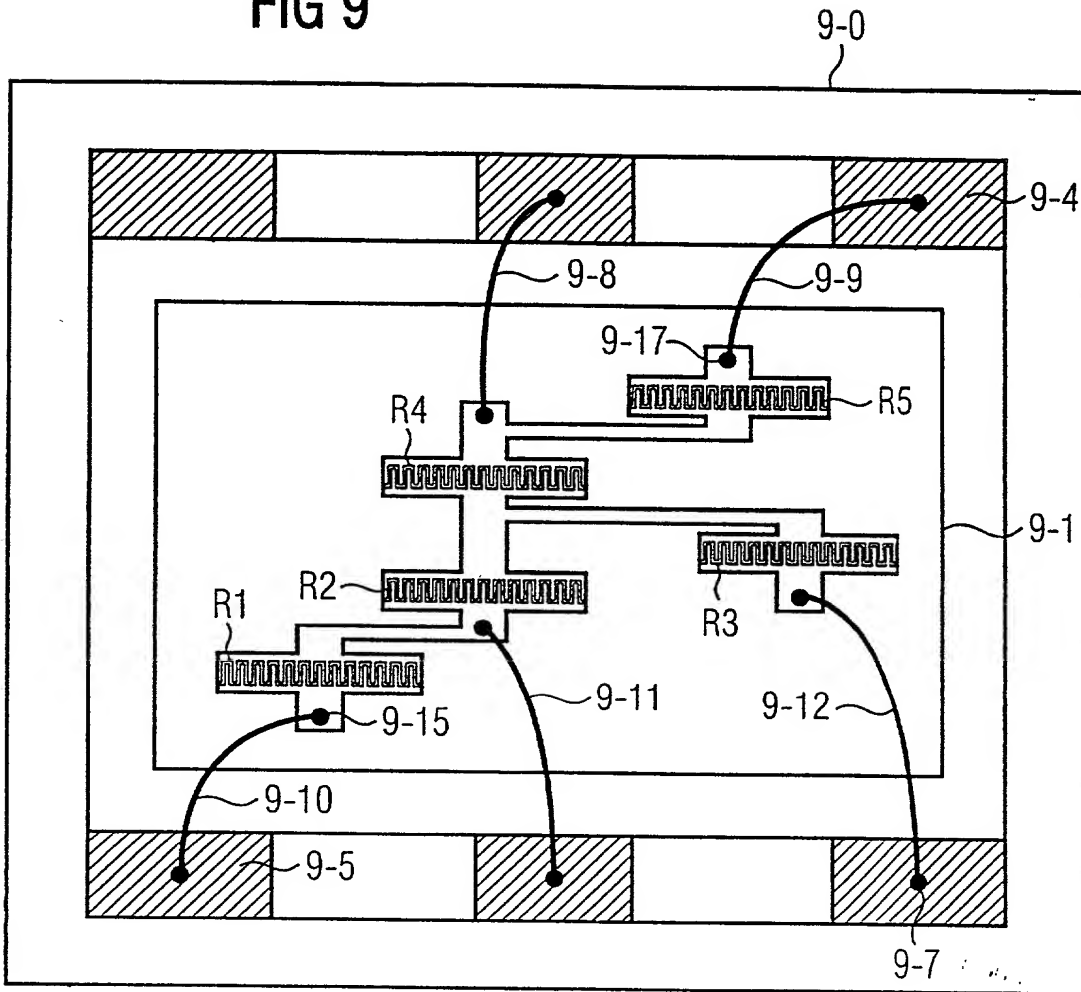
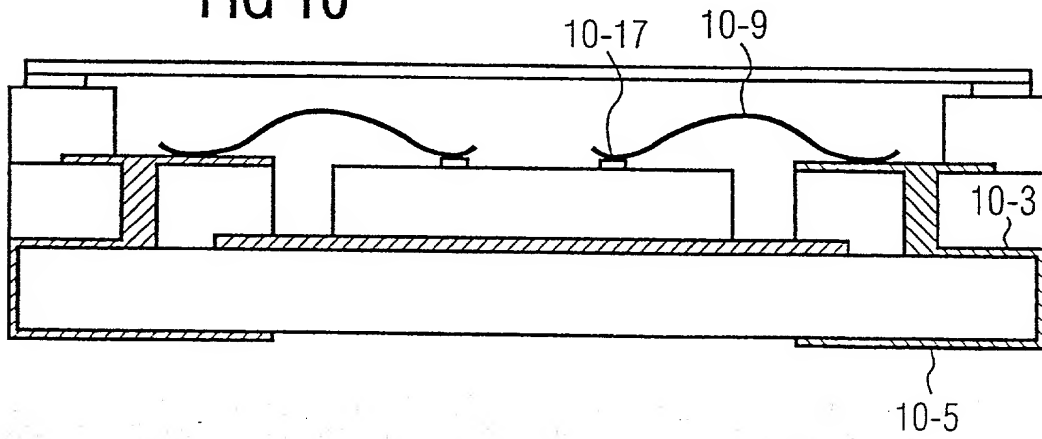


FIG 10



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FIG 11A

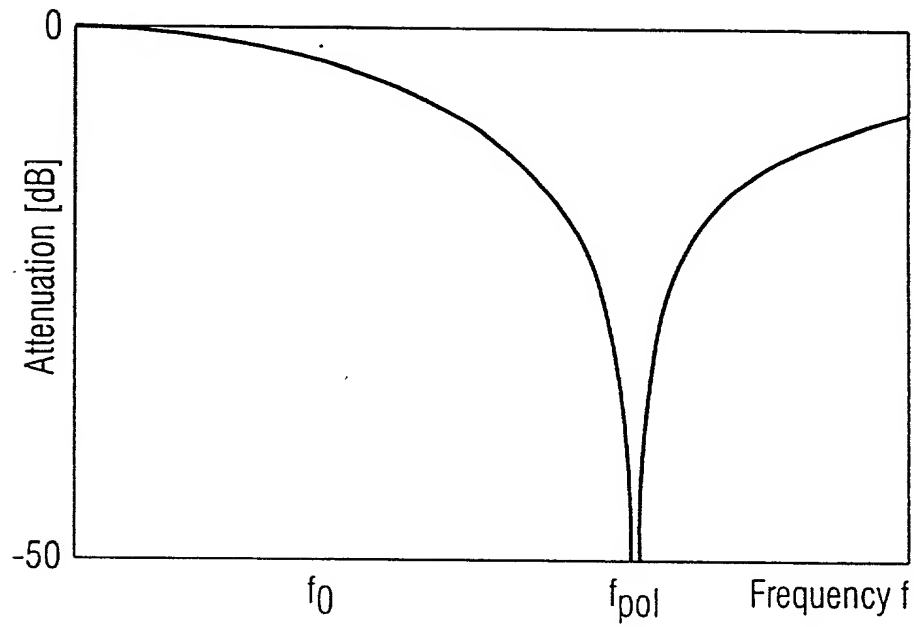
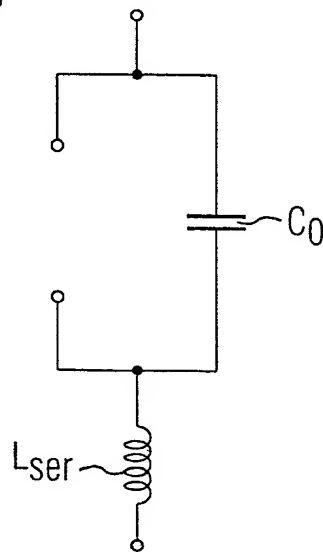


FIG 11B



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FIG 12

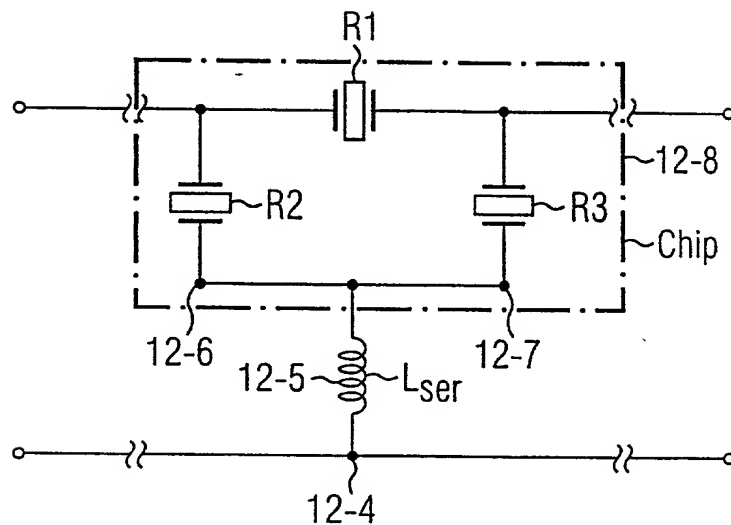
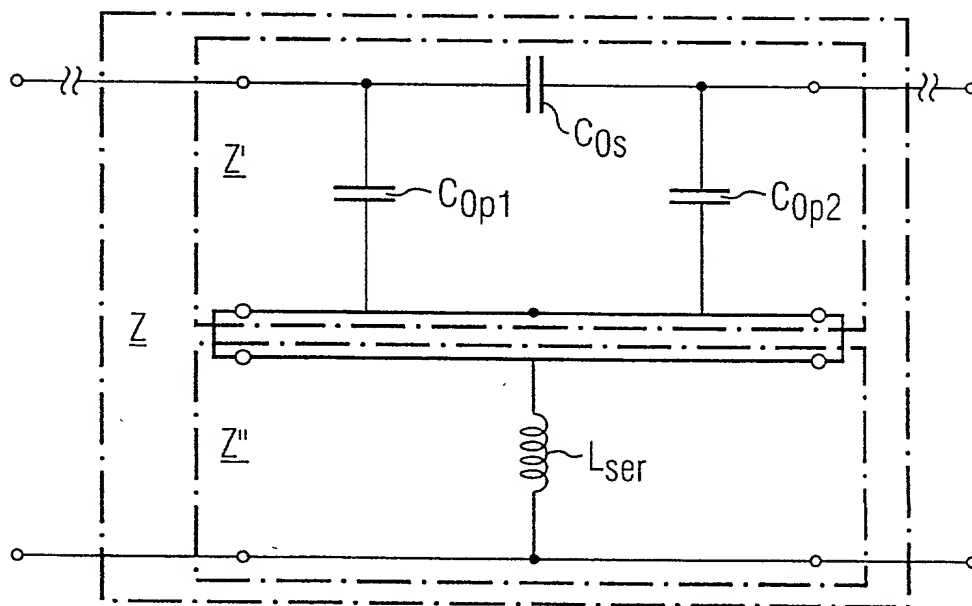


FIG 13



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FIG 14

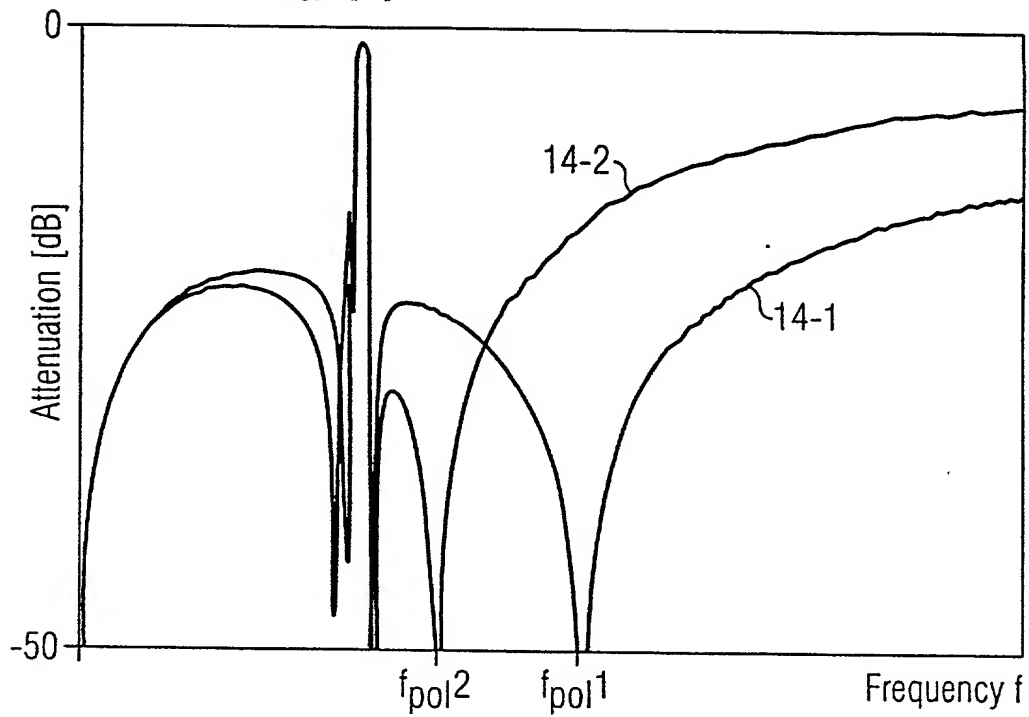
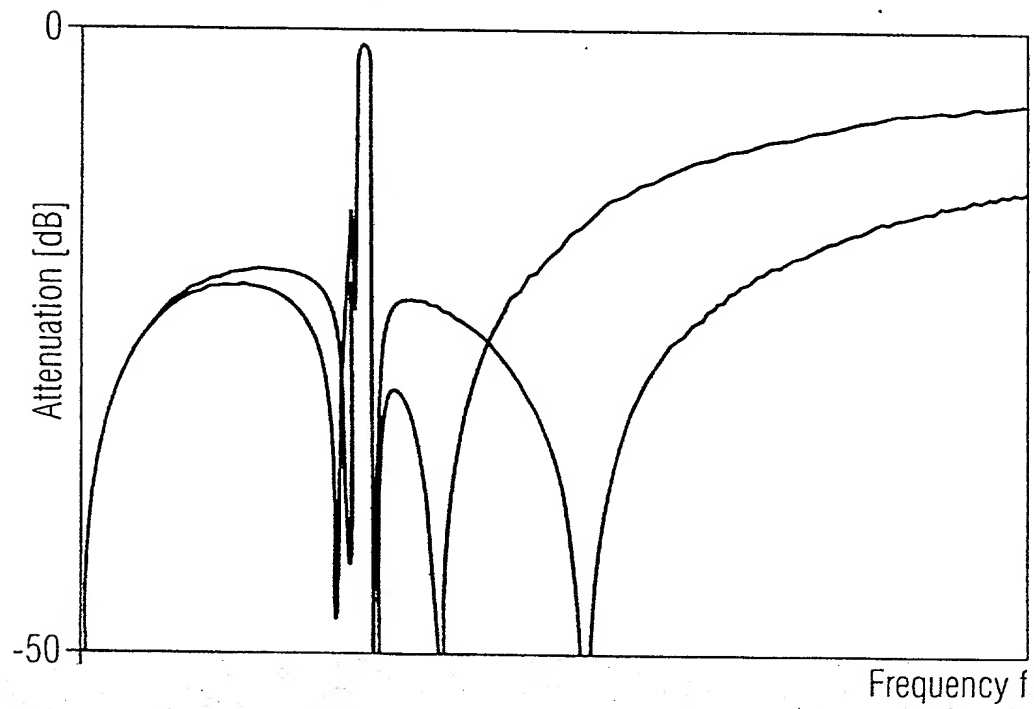


FIG 15



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FIG 16

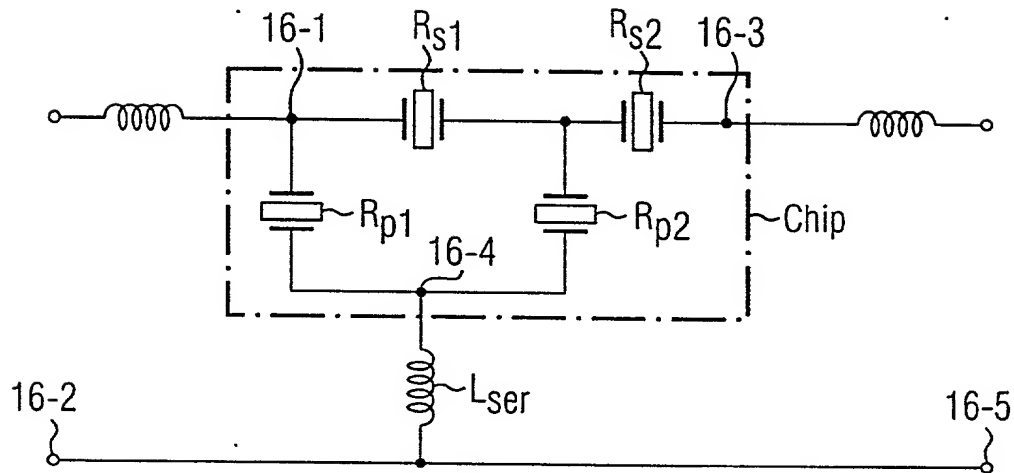
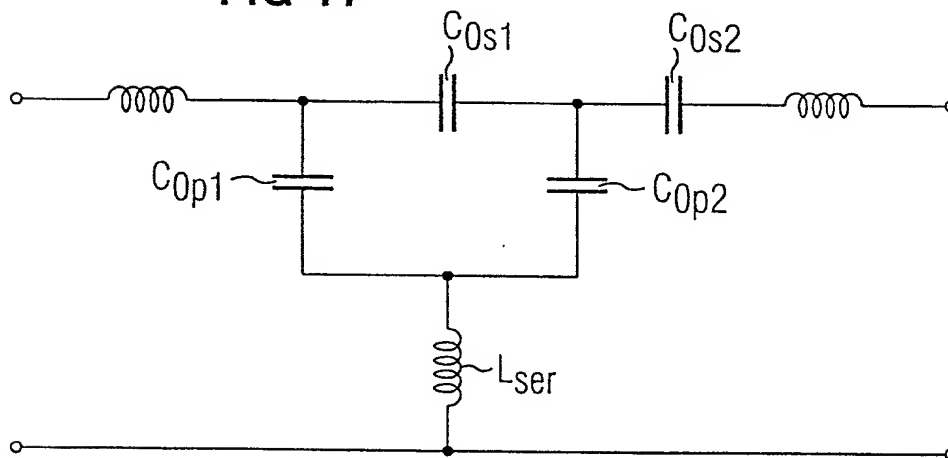
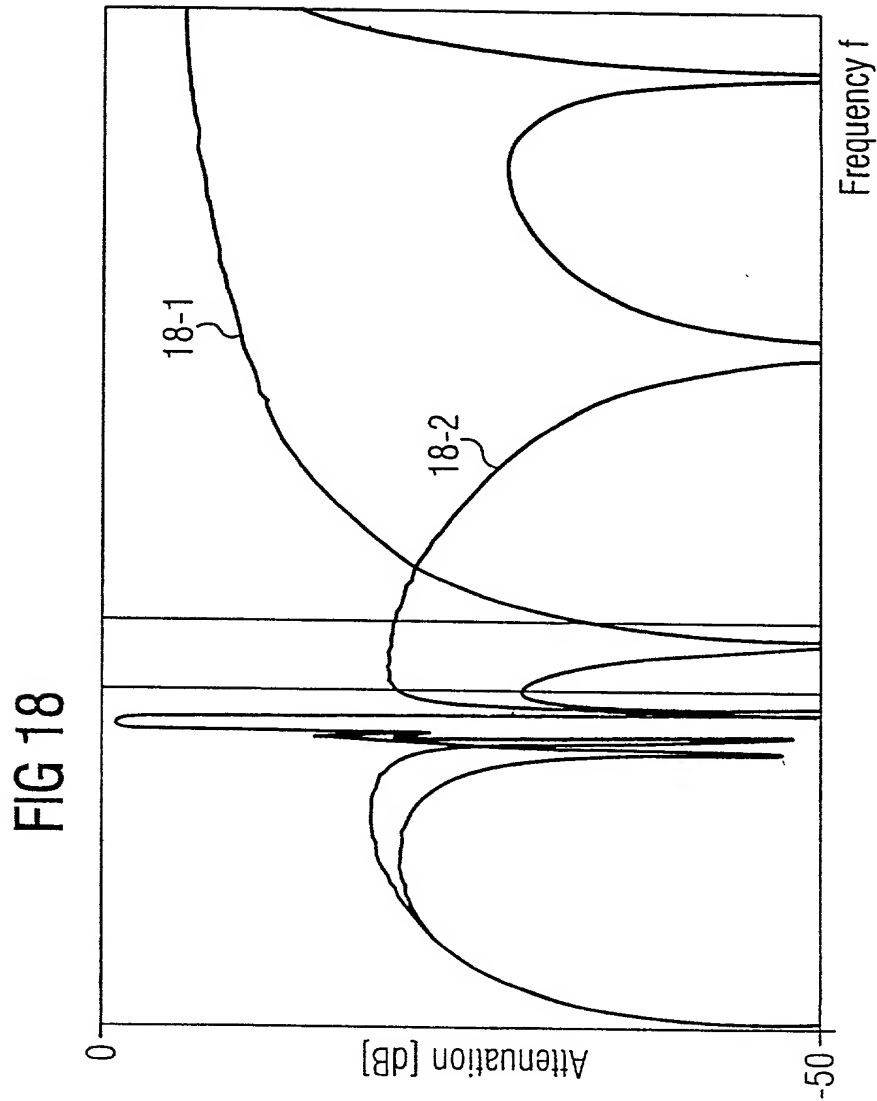


FIG 17



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FIG 19

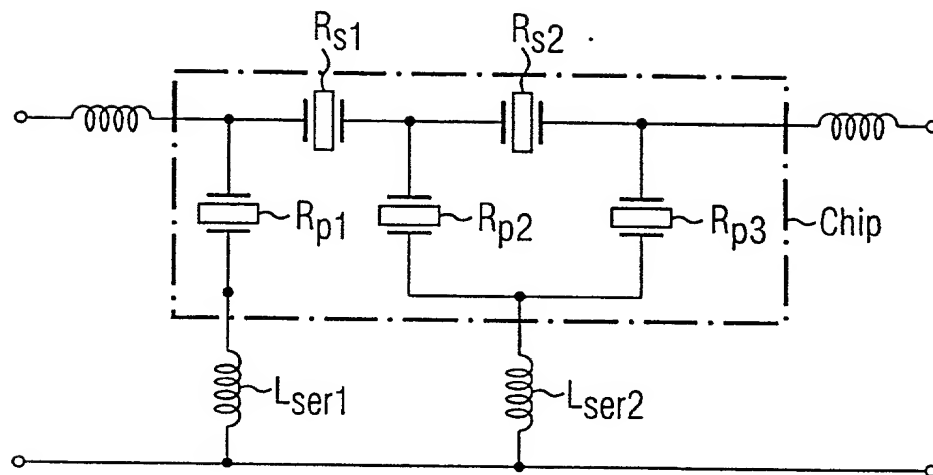
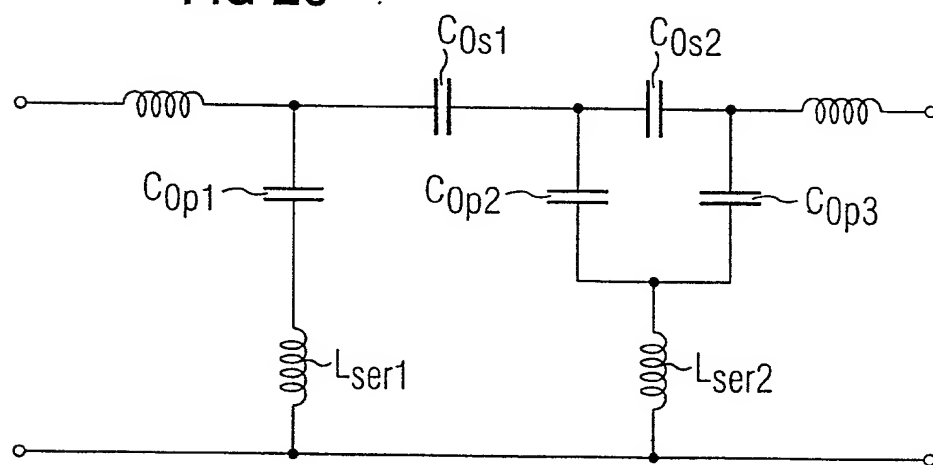
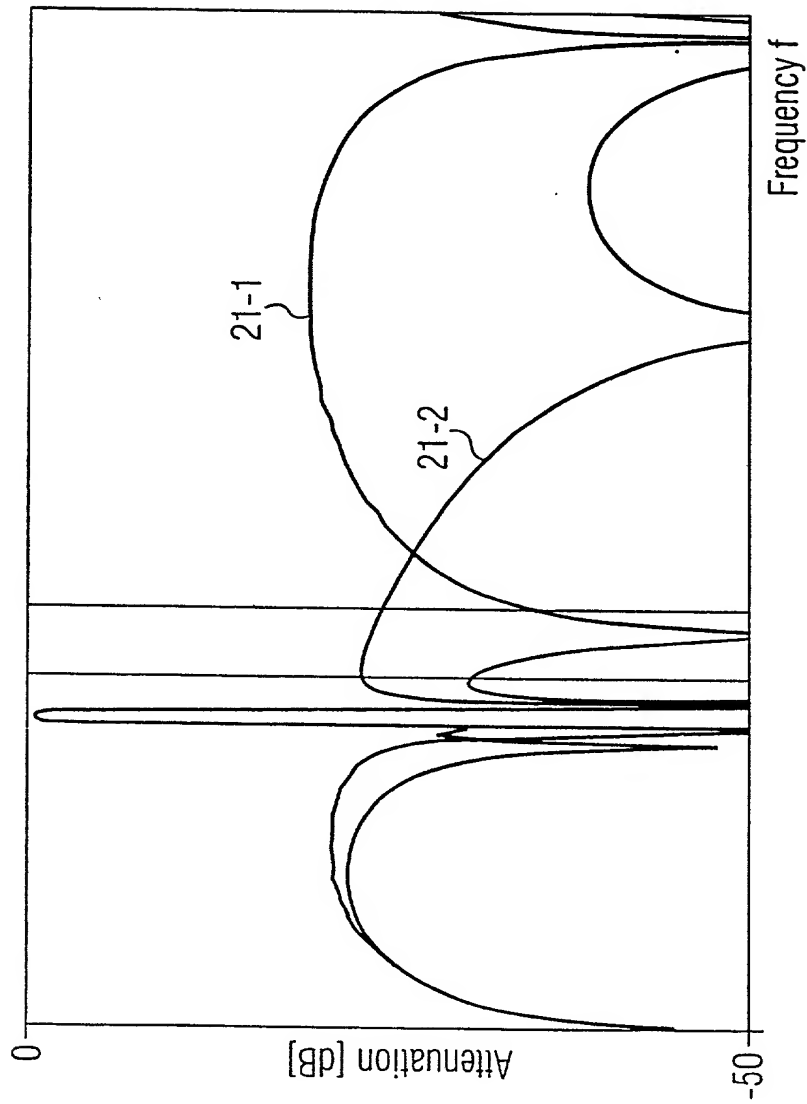


FIG 20



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FIG 21



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FIG 22

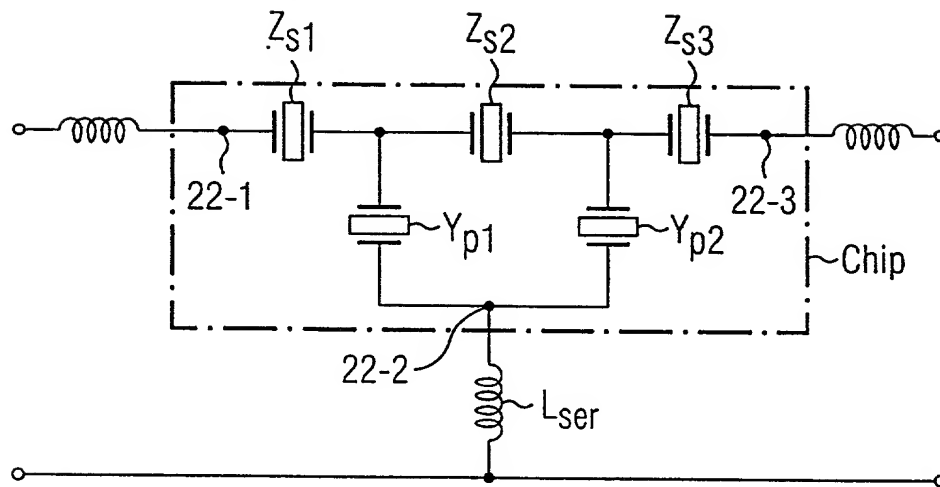
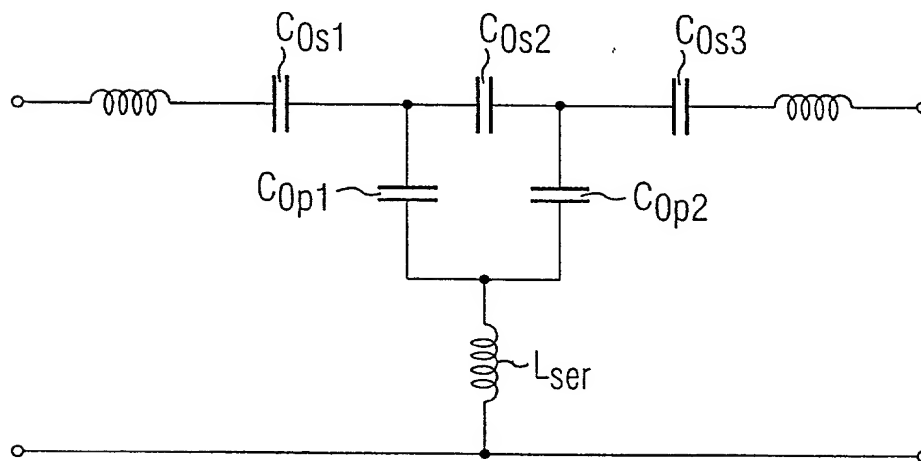
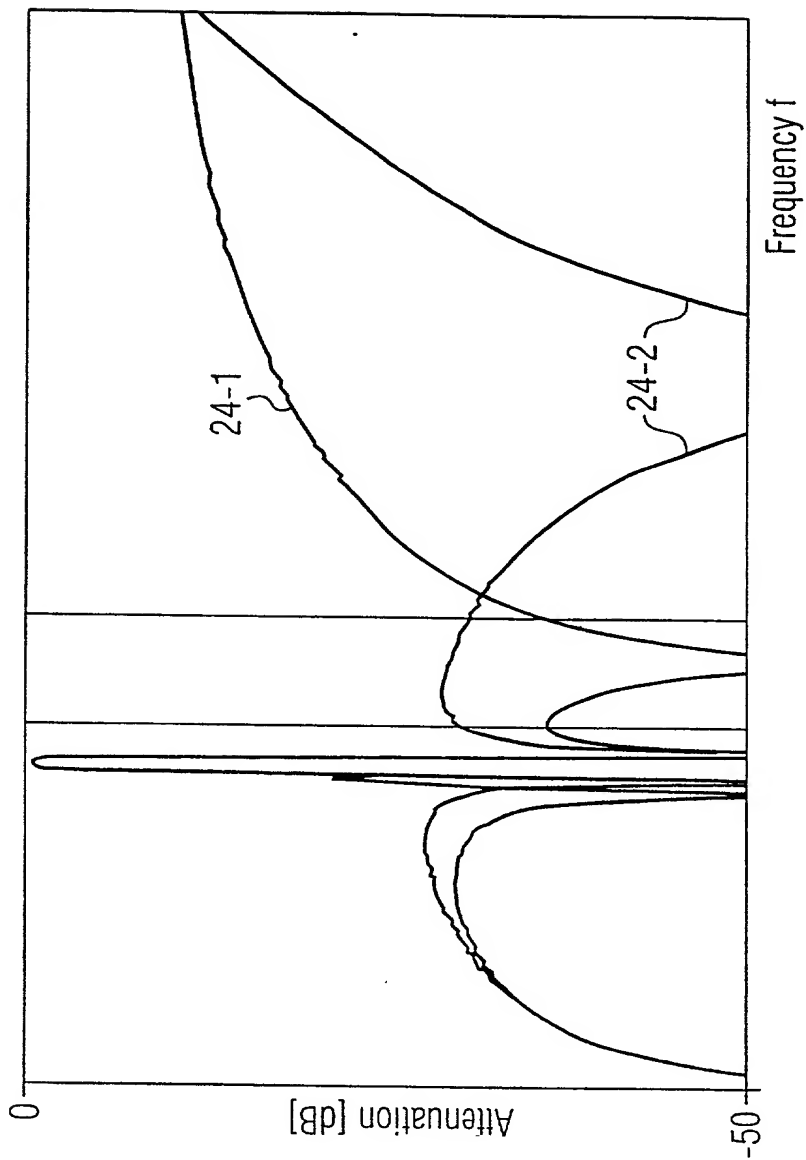


FIG 23



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FIG 24



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FIG 25

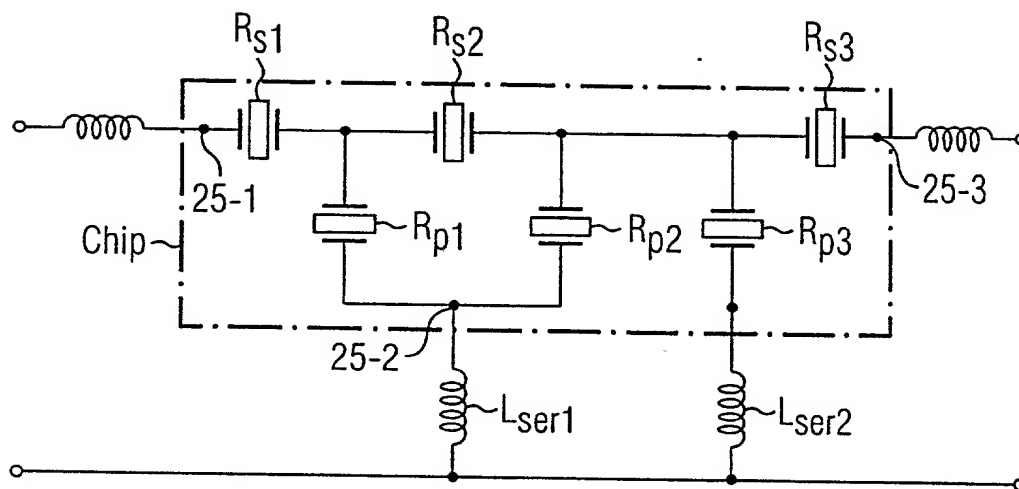
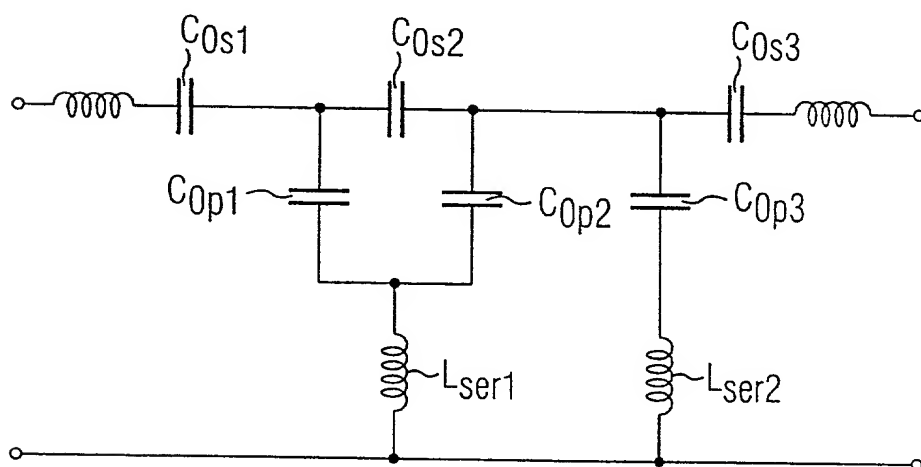
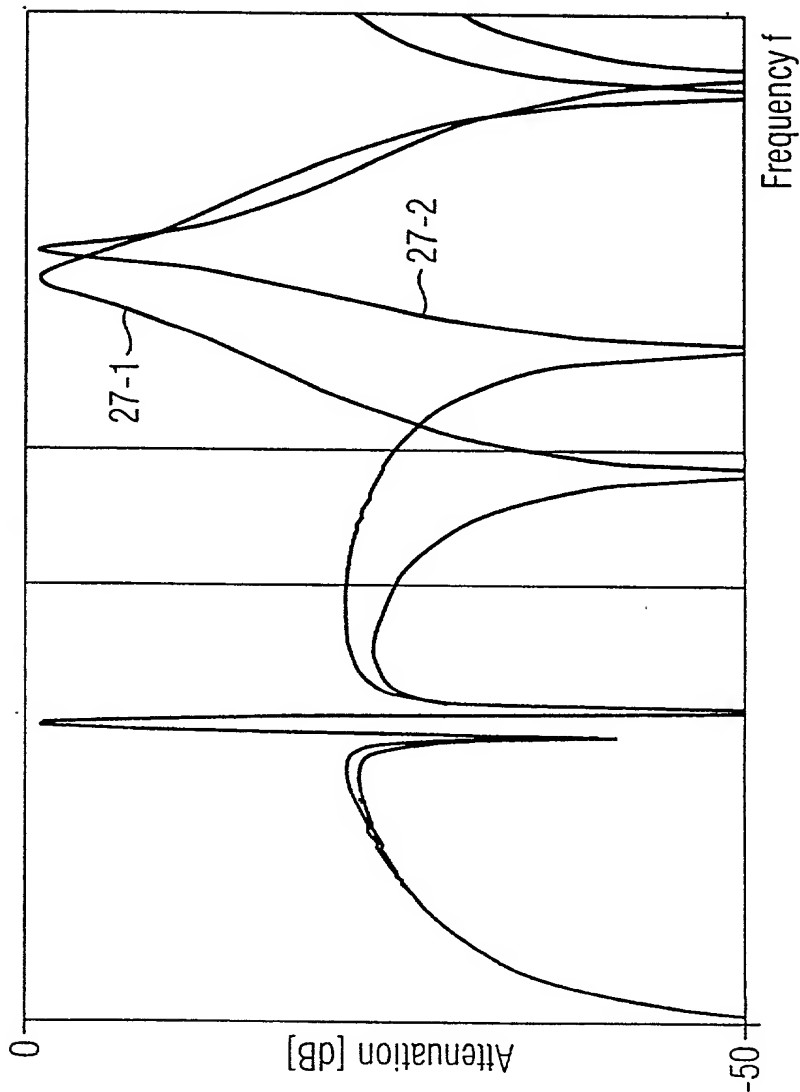


FIG 26



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FIG 27



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FIG 28

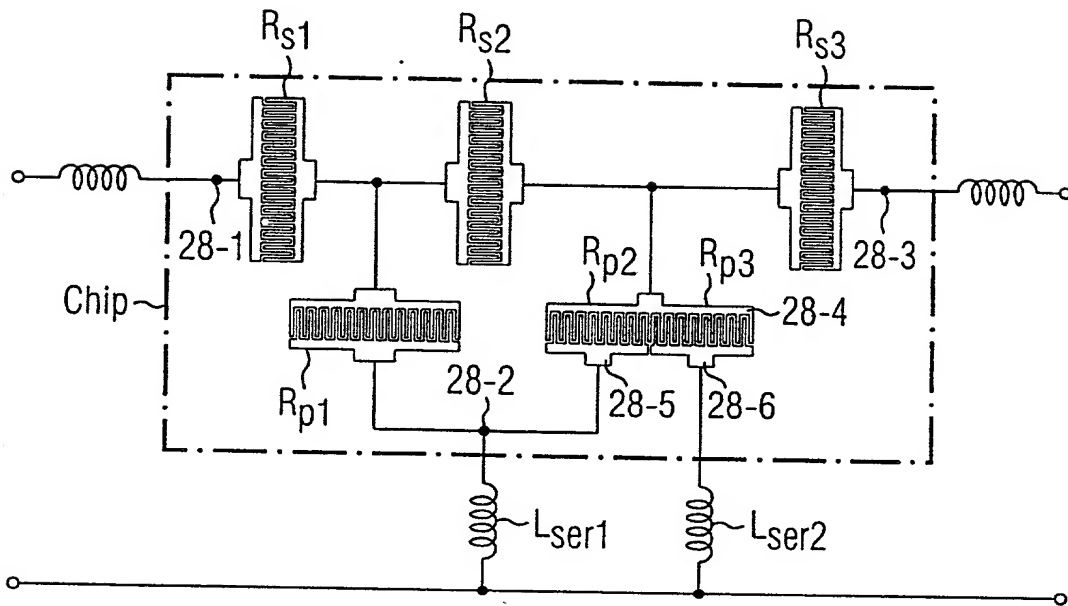
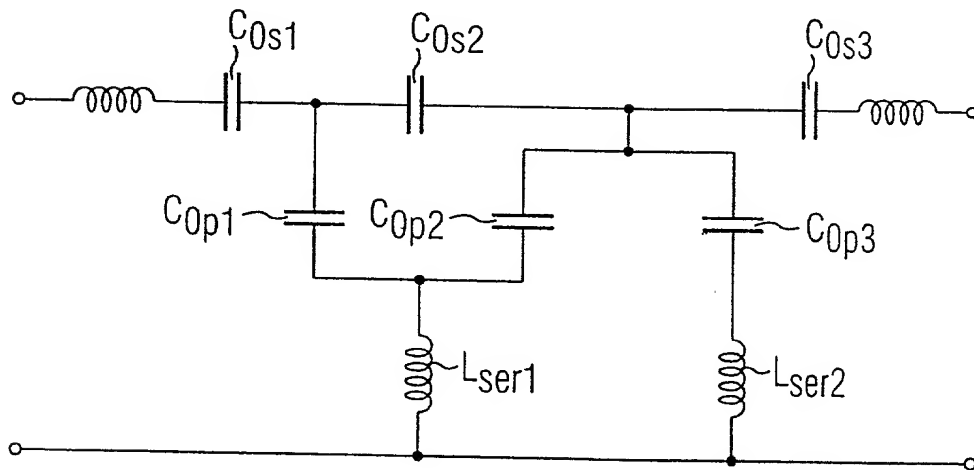
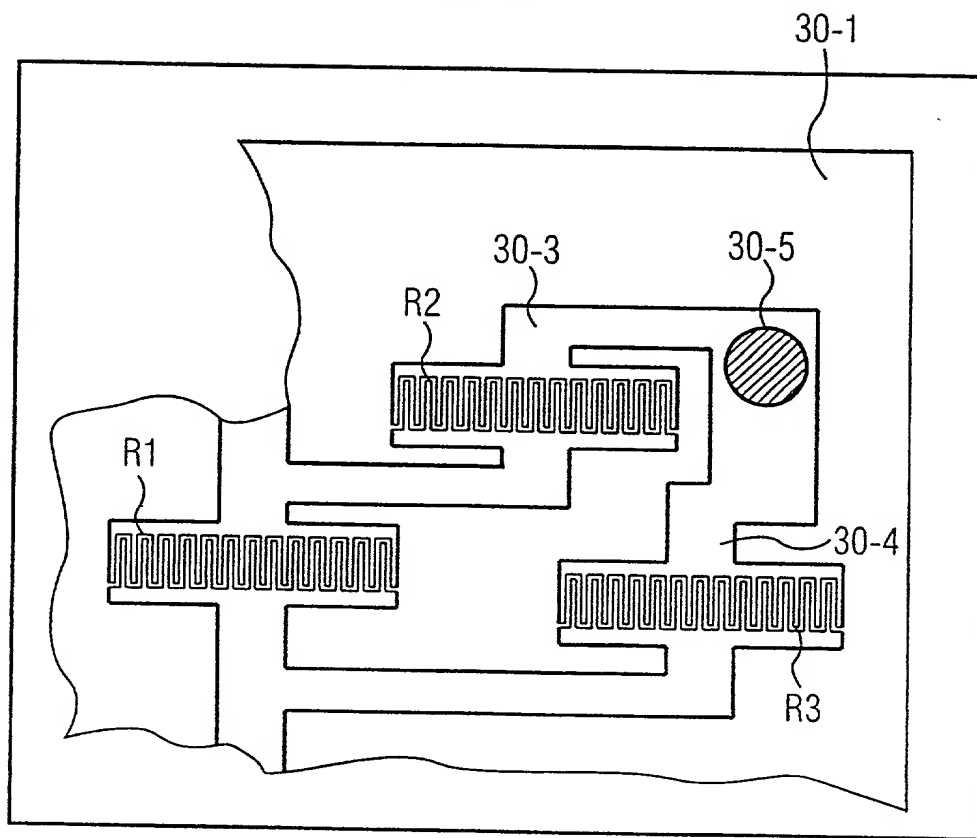


FIG 29



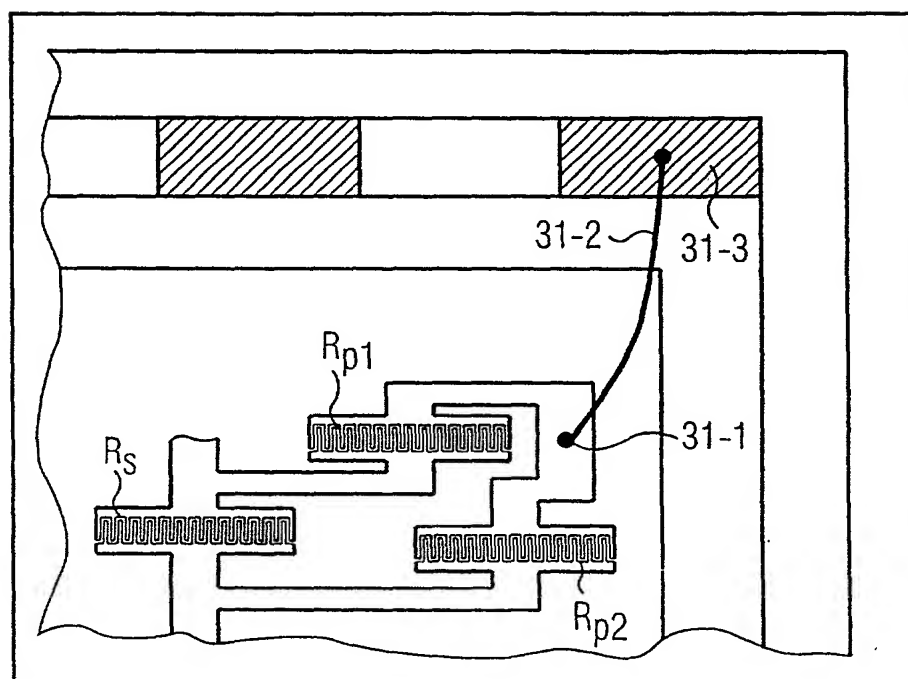
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FIG 30



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FIG 31



DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION
ERKLÄRUNG FÜR PATENTANMELDUNGEN MIT VOLLMACHT
German Language Declaration

Als nachstehend benannter Erfinder erkläre ich hiermit an Eides Statt:

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(zutreffendes ankreuzen)

☒ hier beigefügt ist.

☐ am _____ als
PCT internationale Anmeldung
PCT Anmeldungsnummer _____
eingereicht wurde und am _____
abgeändert wurde.

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As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

**SAW FILTER OF THE REACTANCE FILTER TYPE
WITH IMPROVED STOP BAND SUPPRESSION AND
METHOD FOR OPTIMIZING THE STOP BAND
SUPPRESSION**

the specification of which

(check one)

☒ is attached hereto

☐ was filed on _____ as
PCT international application
PCT Application No. _____
and was amended on _____

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

German Language Declaration

Prior foreign applications
Priorität beansprucht

Priority Claimed

199 32 649.5 GERMANY 13 JULY 1999
(Number) (Country) (Day Month Year Filed)
(Nummer) (Land) (Tag Monat Jahr eingereicht)

☒ ☐
Yes No
Ja Nein

(Number) (Country) (Day Month Year Filed)
(Nummer) (Land) (Tag Monat Jahr eingereicht)

☐ ☐
Yes No
Ja Nein

(Number) (Country) (Day Month Year Filed)
(Nummer) (Land) (Tag Monat Jahr eingereicht)

☐ ☐
Yes No
Ja Nein

Ich beanspruche hiermit gemäss Absatz 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 120, den Vorzug aller unten aufgeführten Anmeldungen und falls der Gegenstand aus jedem Anspruch dieser Anmeldung nicht in einer früheren amerikanischen Patentanmeldung laut dem ersten Paragraphen des Absatzes 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 122 offenbart ist, erkenne ich gemäss Absatz 37, Bundesgesetzbuch, Paragraph 1.56 meine Pflicht zur Offenbarung von Informationen an, die zwischen dem Anmeldedatum der früheren Anmeldung und dem nationalen oder PCT internationalen Anmeldedatum dieser Anmeldung bekannt geworden sind.

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §122 I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

(Application Serial No.) (Filing Date)
(Anmeldeseriennummer) (Anmeldedatum)

(Status) (Status)
(patentiert, anhängig, (patented, pending,
aufgegeben) abandoned)

(Application Serial No.) (Filing Date)
(Anmeldeseriennummer) (Anmeldedatum)

(Status) (Status)
(patentiert, anhängig, (patented, pending,
aufgegeben) abandoned)

Ich erkläre hiermit, dass alle von mir in der vorliegenden Erklärung gemachten Angaben nach meinem besten Wissen und Gewissen der vollen Wahrheit entsprechen, und dass ich diese eidesstattliche Erklärung in Kenntnis dessen abgebe, dass wissentlich und vorsätzlich falsche Angaben gemäss Paragraph 1001, Absatz 18 der Zivilprozessordnung der Vereinigten Staaten von Amerika mit Geldstrafe belegt und/oder Gefängnis bestraft werden können, und dass derartig wissentlich und vorsätzlich falsche Angaben die Gültigkeit der vorliegenden Patentanmeldung oder eines darauf erteilten Patentes gefährden können.

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German Language Declaration

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POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

And I hereby appoint all Attorneys identified by United States Patent & Trademark Office customer number **26574**, who are all members of the firm of Schiff Hardin and Waite.

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| | |
|---|---|
| Voller Name des einzigen oder ursprünglichen Erfinders: | Full name of sole or first inventor: SELMEIER, Peter |
| Unterschrift des Erfinders Datum | Inventor's signature Date <i>Selmeier Peter</i> <i>January, 2nd, 2002</i> |
| Wohnsitz | Residence Maitenbeth, Germany |
| Staatsangehörigkeit | Citizenship Germany |
| Postanschrift | Post Office Address Buchenstrasse 2 |
| | D-83558 Maitenbeth DEX Germany |

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|--|---|
| Voller Name des zweiten Miterfinders (falls zutreffend): | Full name of second joint inventor, if any: |
| Unterschrift des Erfinders Datum | Inventor's signature Date |
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(Supply similar information and signature for subsequent joint inventors).